Experimental Compression of DEHYDRATED FOODS

Miscellaneous Publication 647 *Prepared by*
AGRICULTURAL RESEARCH ADMINISTRATION
UNITED STATES DEPARTMENT OF AGRICULTURE

Washington, D. C., February 1948

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The investigations reported in this publication were conducted by personnel of several of the Bureaus of the Agricultural Research Administration, and of one branch of the Production and Marketing Administration, under the general leadership of C. A. Magoon, of the office of the Research Administrator. G. S. Smith, who was directly responsible for much of the experimental work conducted in the Western Regional Research Laboratory, integrated the technical reports from the several laboratories into a form suitable for publication. The list of cooperators follows:

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EXPERIMENTAL COMPRESSION OF DEHYDRATED FOODS

CONTENTS

INTRODUCTION

Problems of handling, transportation, and storage of foods for overseas shipment during World War II emphasized the need for reducing the bulk of such foods as far as possible. Volume reduction was accomplished to some extent through dehydration. It was clear, however, that further savings in shipping space, storage space, and container materials, as well as greater ease and speed in handling, would be effected if the dried or dehydrated products could be compressed without damage into blocks or units suited to the feeding of large groups of persons, such as the armed forces and civilian populations in areas devastated by war.

The development of satisfactory compression procedures called for considerable research, since there were few precedents on which to draw. Because of the great differences in the physical and chemical properties of foods, each product required individual study to determine its adaptation to compression and the effect of the process on its palatability, rehydration characteristics, nutritive value, and storage life. Various research groups undertook investigations to find solutions to these problems.

This publication reports the results of investigations on compressed dehydrated foods that were undertaken by the Bureau of Agricultural and Industrial Chemistry, through its Western Regional Research Laboratory, Albany, Calif.; the Bureau of Plant Industry, Soils, and Agricultural Engineering, Beltsville, Md.; and the Bureau of Human Nutrition and Home Economics, Beltsville. These investigations were initiated in 1942 at the Western Regional Research Laboratory as an incidental part of a general research program dealing with the production, improvement, and utilization of dehydrated foods. In the course of this program the feasibility of attaining a material reduction in the bulk density of several commodities was demonstrated and tentative compression procedures were developed (*6*).[1] [2]

In October 1943 a more extensive program, designated "The Food Compression Research Project," was instituted under the auspices of the Agricultural Research Administration, and various phases of the projected work were assigned to the three agencies named. The types of products brought under investigation were: Dehydrated vegetables and fruits, spray-dried egg powder, white and whole-wheat flours, rolled oats, soya flour, and pea-soya and cheese-soya soup powders.

In August 1944 the work was discontinued as a war project, partly because a decrease in the need for extreme conservation of shipping space appeared certain, and partly because it was improbable that the results of continued research could be applied in commercial practice at a sufficiently early date to be of significant aid in the handling of war foods. Difficulties in obtaining essential special equipment under war conditions had slowed the progress of the work seriously, and consequently the well-rounded program originally projected had been only partly completed at the time the work was terminated. However, it is believed that the results presented herein, though incomplete, constitute a good groundwork upon which to base further development of food-compression techniques. Further development of commercially practicable procedures for compressing certain commodities in peacetime is believed a possibility, particularly in those instances where cool conditions or refrigeration is required in transporting and storing the food.

DEFINITIONS OF TERMS

Since certain technical expressions used in the discussion of the experimental data may need interpretation, brief definitions of these terms follow.

Block Density.—The apparent density of the compressed food block as determined by its weight and cubic content expressed in terms of pounds per cubic foot. Where the blocks have slightly convex faces maximum dimensions are used to compute volume.

Density Before Compression.—As used in this discussion, the weight of material required to fill, with gentle shaking, a vessel of known volume. Densities of commercial shipments are frequently higher; this is especially true of dehydrated cabbage, which is generally compacted to a density of 20 to 22 pounds per cubic foot in the commercial 5-gallon container. Densities of commercially packed fruits are also higher because pressing or other debulking (bulk or volume reducing) procedures are usually employed during packaging.

Dwell.—The length of time the maximum pressure is applied to the block.

Fines.—The smaller fragments of dehydrated vegetable that are formed by the breaking or crushing of the product under certain compression conditions or during handling.

Moisture Content.—Expressed here on the moist-weight basis. The moisture content of egg powder was determined by methods prescribed in current United States Quartermaster Corps specifications.[3] The procedure for dehydrated vegetables involved determination of the loss in weight upon drying finely ground samples in a vacuum for 16 hours at 70° C. (158° F.), according to directions given in a previous publication (*5, pp. 145–146*). The moisture content of fruits was determined by the same procedure except that the samples were passed through a hand meat grinder instead of being reduced to a powder. Moisture in cereal and soya products was determined according to methods of the Association of Official Agricultural Chemists.

Nip Period and Clear Period.—Respectively, the time required to build up pressure from a barely perceptible value to the ultimate attained, and the time elapsed in reducing the pressure to zero. Recording of these factors, especially nip, was considered important in the compression of egg powder. Under certain conditions short nip periods had a tendency to cause air entrapment, which subsequently resulted in the cracking of the egg-powder block. Where nip and clear periods are not given the time was generally the minimum attainable with the equipment employed. In such cases the nip period ranged from about 2 to 10 seconds, depending on the equipment and height of fill, and the clear was practically instantaneous.

Organoleptic Quality.—The acceptability of the material after preparation as a cooked but unseasoned food. Tests determining organoleptic quality take

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[1] Italic numbers in parentheses refer to Literature Cited, p. 57

[2] U. S. Department of Agriculture, Western Regional Research Laboratory. information sheet on compression of dehydrated fruits and vegetables. U. S. Bur. Agr. and Indus. Chem., Inf. Sheet AIC–5, [5] pp. 1943. [Mimeographed.]

[3] [U. S. Army] Quartermaster Corps (Subsistence Laboratory). tentative specification for egg, powdered. CQD No. 117, No. 117A, 9 pp. 1943–44. [Mimeographed.]

into consideration the combined effects of such characteristics as taste, flavor, color, texture, and general appearance.

Percentage Volume Reduction.—The term applied to the quotient determined by the formula

$$\frac{V_1 - V_2}{V_1} \times 100$$

where V_1 is the volume of the uncompressed material, and V_2 is the final volume of the compressed block. In terms of density the percentage volume reduction is

$$\frac{d_2 - d_1}{d_2} \times 100$$

where d_1, is density of the material before compression and d_2 is the density of the compressed block.

Pressure.—The maximum force, in pounds, applied per square inch of the block face in contact with the moving die.

Reconstitution.—The process of preparing dehydrated foods for use by restoration of water (rehydration).

Rehydration Ratio.—The absolute gain in weight by the dry sample through the absorption of water during reconstitution; defined as the ratio of the weight of the rehydrated material to the weight of the dried material from which it is derived.

Wet-Bulb and Dry-Bulb Temperatures.—Readings of wet-bulb (t_w) and dry-bulb (t_d) thermometers in the conditioning cabinets and dehydration equipment. The difference in the readings gives a measure of the humidity of the air and its dehydrating effectiveness.

GENERAL PROBLEMS IN FOOD COMPRESSION

The production of satisfactory compressed dehydrated food products is influenced by a number of factors, among which the following are of chief importance.

Breakage and the Production of Fines

Under certain conditions the compression of dehydrated foods results in breaking and crushing of the food pieces or particles. With such products as powdered soups, flour, and powdered eggs, this does not present a problem, but with other foods breakage and crushing can seriously detract from the quality of the reconstituted dehydrated product.

Crushing, and sometimes breakage, may result in the formation of powdery material, or fines. A considerable amount of fines can so alter the character of the cooked material as to be very objectionable. As an example, the production of fines in dehydrated potatoes causes the liberation of free starch through fracturing of cells. When the material is reconstituted and cooked, the starch swells and gives the product a waxy or pasty character which greatly detracts from its palatability. In cabbage also a large percentage of fines is highly objectionable. In fact, for best texture a low percentage of fines is necessary in all dehydrated vegetables.

The moisture content, the presence of natural sugars and other chemical constituents, and the temperature at which compression is done all affect the plasticity of the material and thus influence the amount of fines produced. The effect of these factors will be considered further in the discussion of the compression characteristics of the specific food products.

One of the objectives of the compression experiments was to determine conditions that would hold production of fines to less than 5 percent in products susceptible to damage through breakage and crushing. With several commodities the compression procedures developed resulted in no detectable increase in fines.

The proportion of fines in compressed vegetable blocks was determined by soaking the samples in water long enough for them to disintegrate, separating the fines by means of a 4-mesh sieve, and calculating the percentage. The blocks were rehydrated for 16 hours in cool water, and the fines were then separated, dried, and weighed. The percentage was determined after an appropriate correction had been made for the loss of soluble solids, through the use of a predetermined factor. In some preliminary tests, where more speed and less accuracy were required, water at about 150° F. was used in the soak, which brought about disintegration in less than 1½ hours. The fines separated with a 4-mesh screen were then measured by volume in the wet condition.

No satisfactory direct method has yet been developed for determining the percentage of fines in rehydrated compressed cabbage and onions. With these products organoleptic tests appeared to be reasonably dependable criteria of the amount of fines present. Excessive fines in compressed cabbage and onions result in reconstituted products that differ considerably in texture and appearance from the reconstituted uncompressed material. Consequently, the percentage of fines produced during compression of these two commodities was judged to be satisfactorily low when the uncompressed and the compressed products were indistinguishable in these respects.

Besides producing fines, compression under undesirable conditions can bring about breakage or fragmentation of the food piece not necessarily accompanied by the formation of an undesirably large amount of fines. Breakage can, however, have a deleterious effect on organoleptic quality. For example, breakage of skins or pits of fruits occurs under some compression conditions, and this obviously reduces the acceptability of the product. With diced, sliced, or stripped vegetables, the eye appeal of the reconstituted product is considerably greater when the food pieces are whole and clean-cut than when they are broken and not of reasonably uniform size. Therefore compression conditions resulting in the least possible breakage were sought. The criterion employed in determining whether or not excessive breakage occurred consisted in simply comparing the appearance of reconstituted samples of the uncompressed and compressed material. When the compressed sample compared favorably with the uncompressed, breakage was considered to be satisfactorily low. This test actually comprised a part of the more general organoleptic test.

COHERENCE

Good coherence in compressed food blocks is generally a requirement. It facilitates packaging and later handling. The ease with which satisfactorily cohesive blocks of different foods are formed varies with their individual characteristics of physical structure and chemical constitution. It is considerably influenced by the moisture content of the material, by its temperature at the time of compression, and to some extent by the way the pressure is applied. In compressing powders, if pressure is applied too rapidly or provision has not been made for the escape of occluded air, the block is likely to crack or shatter when pressure is released.

Blocks of dehydrated foods have a tendency to expand more or less after removal from the press. Because expansion has a tendency to reduce the cohesiveness of the block, conditions that will hold expansion to a minimum are usually selected. In general, longer dwell periods tend to decrease the tendency to expand. Short dwells, however, favor high production and can be used in practice provided expansion is restricted by placing the blocks under restraint shortly after they are ejected from the press. With some products this restraint may be applied in the form of suitable wrappings. In other cases expansion can only be prevented through the use of holding presses designed to hold the blocks under light restraint until they have cooled to near room temperature. Blocks of all products except certain fruits lose practically all tendency to expand when cool. Descriptions of suitable holding presses are given later in connection with a discussion of procedures and equipment.

With dried apricots, peaches, prunes, and cranberries, the initial cohesion is not permanent, and packaging in containers of considerable rigidity is required to retain block form and size. Egg powder containing 2 percent moisture also presents a problem, since the compressed blocks often are not satisfactorily cohesive. Compression of the material directly in the final container appears to be one possible way of overcoming this deficiency. Such special cases will be considered later when discussing the compression characteristics of the individual commodities.

DENSITY

From the standpoint of saving storage and shipping space maximum reduction in bulk is desirable, but several practical considerations must be taken into account. In some cases the formation of blocks of the highest possible density is not desirable because palatability and nutritive values are adversely affected and the permeability of the block is so reduced as to render rehydration very difficult. Higher densities are generally effected through the use of higher pressures and longer dwells, which increase the cost of the press operation. There is a degree of density beyond which it is not profitable to go, the greater density obtained at higher pressures and longer dwells not being sufficient to warrant the higher cost. In the experimental work and in the tentative procedures set forth here, these and related matters have been taken into consideration.

REHYDRATION OF COMPRESSED FOODS

Matters related to the rehydration of compressed dehydrated foods are of practical concern to prospective users of these foods. If long soaking is required, the element of convenience is lost and the leaching out of valuable constituents into the water reduces the nutritive value of the food. The length of time required for rehydration should not materially exceed that needed for rehydrating the uncompressed product. In the work reported here, the effort was made to determine conditions under which satisfactory reduction in bulk could be effected with a minimum of time required for rehydration.

Where the blocks could readily be broken up by hand without damage to the material, it was found that the same reconstitution procedures could be applied to the compressed foods as to the uncompressed. If, however, the individual particles were cemented together to a considerable degree, it was found desirable to disintegrate the blocks by soaking them in water.

The time required for disintegration by soaking depends, it was learned, on the physical properties of the blocks, and consequently it varies with different products. Producing blocks that will completely disintegrate after soaking for 1 hour or less appeared to be a desirable aim. One-pound blocks fulfilled this condition in all cases.

Some products were found to require soaking in hot water to insure rapid disintegration. In most of the cases where soaking in hot water for a considerable time was necessary it was found desirable to avoid block densities in excess of 60 pounds per cubic foot. Blocks with higher densities generally retain a dry core, and the heat tends to impart an undesirable scorched taste to the dry material.

Once the blocks are completely disintegrated the cooking procedures applicable are practically the same as for the uncompressed material. Experiments concerned with the determination of best methods for rehydrating the products will be discussed later.

Size and Shape of Food Blocks

Number of persons to be served is probably of first importance among the factors determining the most desirable size of food block. Other factors include the character of the food, its adaptation to compression, and the ease with which reconstitution is effected. From the standpoint of the food manufacturer the productive capacity of the food press is of great importance, for economy of operation demands reasonably large output. The rate of production of compressed blocks is limited primarily by the speed of press charging, compressing, and ejecting motions. Within the working range of a given press large or small blocks can be produced at nearly the same rate. Consequently, the production capacity of a single-block press on a weight basis depends considerably on the weight of the block produced. The sizes and costs of similar presses are closely related to the size of the block that can be handled, and these factors should be considered in determining the size of block to be produced.

Blocks of a size to provide 50 servings were proposed for army use. For the majority of the commodities studied such units weighed from 1 to 3 pounds, and these sizes appear practical from the standpoint of ease of rehydration and packaging.

Much heavier blocks were suggested for egg powder, and blocks weighing as much as 14 pounds were made in a 10- by 7¼-inch mold. These were satisfactory from a usage standpoint, as portions could be removed from the block as needed. Large blocks of dehydrated apricots, peaches, and prunes are also practical because they lose coherence when removed from the boxes required for their packaging and the desired portions can be easily broken off. Blocks of these fruits weighing 16 pounds were made in the course of the studies. It is doubtful, however, that large units of such very cohesive materials as dehydrated onions, apple nuggets, etc., would prove practical because of difficulty in removing portions and the slowness with which they disintegrate when the entire block is rehydrated. Also, where it is necessary to heat the material before compression it would be difficult to cool very large blocks fast enough to prevent heat damage. Blocks of most of the products studied weighed from 2 ounces to 2 pounds.

Food blocks may be of various shapes, depending on the character of the material, but the rectangular form is preferred because it is easy to wrap and handle and economical of space. In the experiments the ratio of block width to length varied from 1 to 0.5, and that of thickness to width from 0.3 to 0.8. These proportions were usually found satisfactory. Rectangular molds ranging in cross section from approximately 3 by 5 to 6½ by 4¼ inches were employed for blocks weighing 1 or 2 pounds. A cylindrical mold 2¼ inches in diameter and a rectangular mold 2 by 3 inches were used in preliminary laboratory tests.

Mechanical strength of the block is an important consideration, but blocks should be as thin as permissible in order to facilitate both post-compression cooling and disintegration during reconstitution. A few preliminary experiments indicated that wafer-thin blocks (about one-eight to one-quarter inch thick) can be formed successfully from vegetable strips or dice without excessive fragmentation, and that these disintegrate very readily in water. A special type of press might be visualized in which a continuous sheet of such compressed material could be formed and cut into rectangular pieces which could be stacked to form bricks weighing 1 or 2 pounds each.

Food blocks are usually formed in molds so designed that the moving die strikes the block face having the largest area. Although a greater force is required to exert a given pressure on the larger area, this design has distinct advantages. The mold cavity is more easily charged, a comparatively shallow mold box may be used, and the distance the ram must travel is reduced. These factors permit reduction in press size

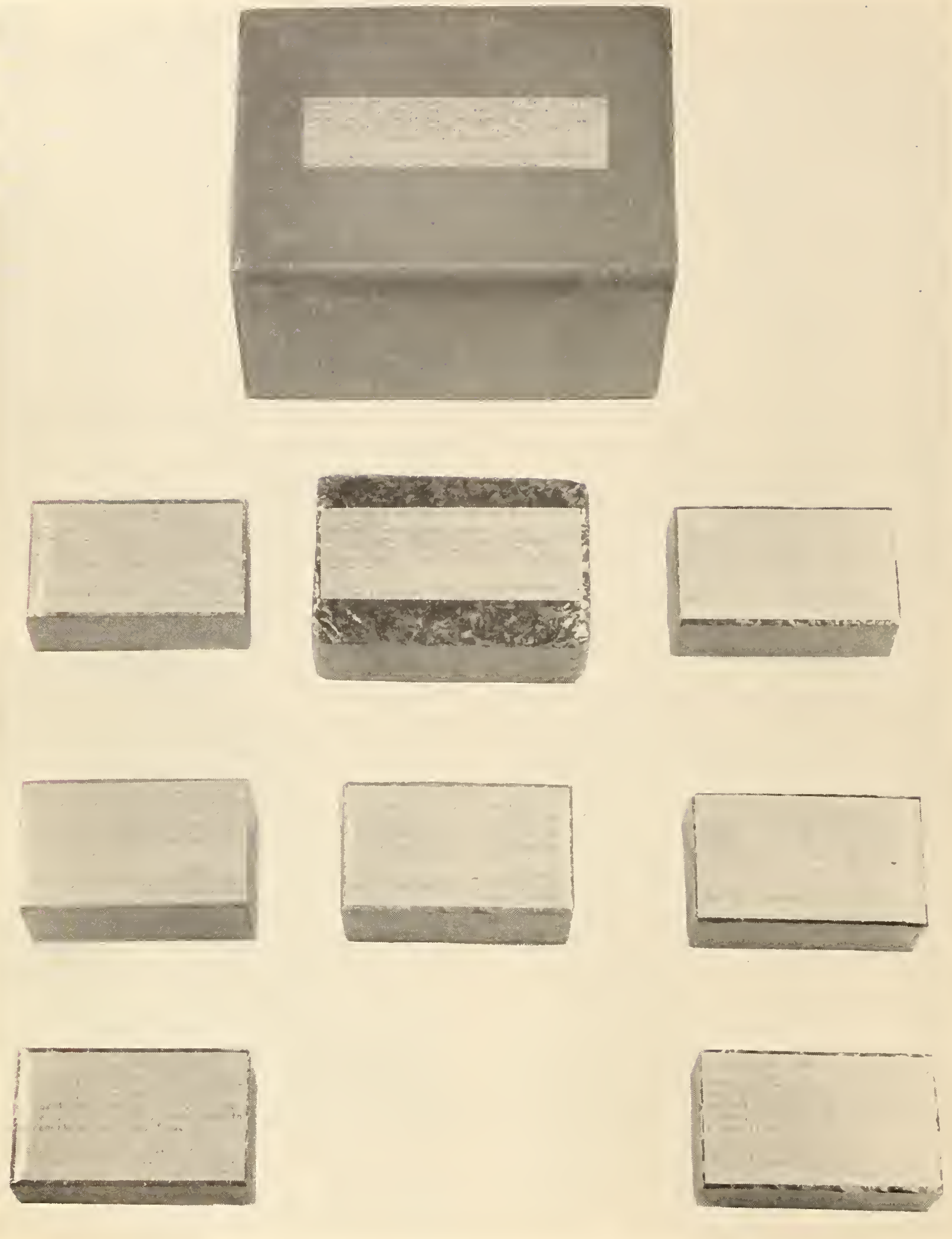

Figure 1.—Typical food blocks prepared in the experiments. The smallest blocks weigh 1 pound and measure approximately 3 by 5 by 2 inches. The large block measures approximately 7 by 10 by 6 inches and contains 14 pounds of egg powder. All blocks are wrapped in heat-sealed cellophane.

and effect savings which tend to compensate for higher hydraulic pumping costs.

For a given compression procedure the area of the pressing face of the block is limited by the force that the press can exert. Choice of block shape may frequently be limited when compressing a block of large volume at high pressure if the press is not designed for the work. If the press cannot exert sufficient pressure, use of one of the smaller surfaces of the block as the pressing face may sometimes be permissible. However, this practice is definitely limited by the depth of the mold box, the length of the press ram, and the compression and flow characteristics of the commodity handled. In practically all the work reported here the block surface with the largest area was used as the pressing face.

Typical blocks of different commodities are shown in figure 1.

Organoleptic Quality

Obviously little would be gained by compressing dehydrated foods if palatability were substantially lowered in the process. When foods have lost their taste appeal, much of their value is gone. Physical damage and exposure to conditions that bring about chemical change can seriously affect the texture, color, taste, flavor, and appearance of dehydrated foods. The organoleptic quality of the products, both before and after compression, was therefore carefully studied. The scoring was done by tasting panels, the members of which had considerable experience and training in evaluating dehydrated foods. The methods employed in determining organoleptic quality and the results obtained with the various commodities will be discussed in later sections.

Storage Life

It is well known that deterioration of organoleptic quality and nutritive values occurs when dehydrated foods are stored at normal temperatures for prolonged periods. Naturally it is highly desirable that the rate of deterioration be no greater for a compressed product than for the uncompressed.

Two questions arise from speculation as to whether compression leads to a change in storage properties. (1) Does compression reduce the oxygen content of hermetically sealed containers sufficiently to improve storage properties? (2) Is there a change in storage properties due to the more intimate contact of dissimilar components in compressed material?

With reference to the first question, it should be mentioned that gas packing in sealed metal containers is now required for cabbage, carrots, and certain other dehydrated foods sold under Government contract. Flavor, color, and vitamins are retained longer through the elimination of oxygen and its replacement with an inert gas. Gas-packing procedures prescribed in Government specifications are directed toward the attainment of package atmospheres containing not more than 2 percent oxygen.

The reduction in oxygen content brought about by compression can readily be calculated. Uncompressed dehydrated diced carrots, for example, are commercially packed 20 pounds to the 5-gallon can. A 5-gallon can, if allowance is made for 10 percent of unused space, will contain 39 pounds of the material in block form (block density, 65 pounds per cubic foot). Then, taking 95 pounds per cubic foot as the true density of the dehydrated product, simple calculations show that the amount of oxygen present per unit weight of food for loose and compressed packs that contain air, and for loose and compressed material packed in gas with a 2-percent oxygen content will be as follows:

	Oxygen	
Type of pack:	*Cubic feet per 100 pounds of food*	*Ratio* [1]
Loose, air	0.48	37
Compressed, air	.14	11
Loose, gas	.046	3.5
Compressed, gas	.013	1.0

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[1] Amount of oxygen present per unit weight of food, on basis of that in compressed gas pack.

From these figures it is apparent that compression of carrots effects a more than threefold reduction in the amount of oxygen available per unit weight of food. It would seem possible that this could result in improved storage properties in both air packing and gas packing. At the same time it is seen that packing the loose material in gas is considerably more effective in reducing the amount of oxygen than is compression alone.

With regard to the second question, it is obvious that compression does result in much closer contact of food pieces and particles, and it is conceivable that such contact may have an effect on storage life. This might apply, for example, in instances where the food material is made up of several components, one of which possesses antioxidant properties. Also, it is possible that one component might contain a substance that would hasten the deterioration of other components, and that more intimate contact would intensify this effect.

These possibilities indicated that it was advisable to investigate the relation between compression and

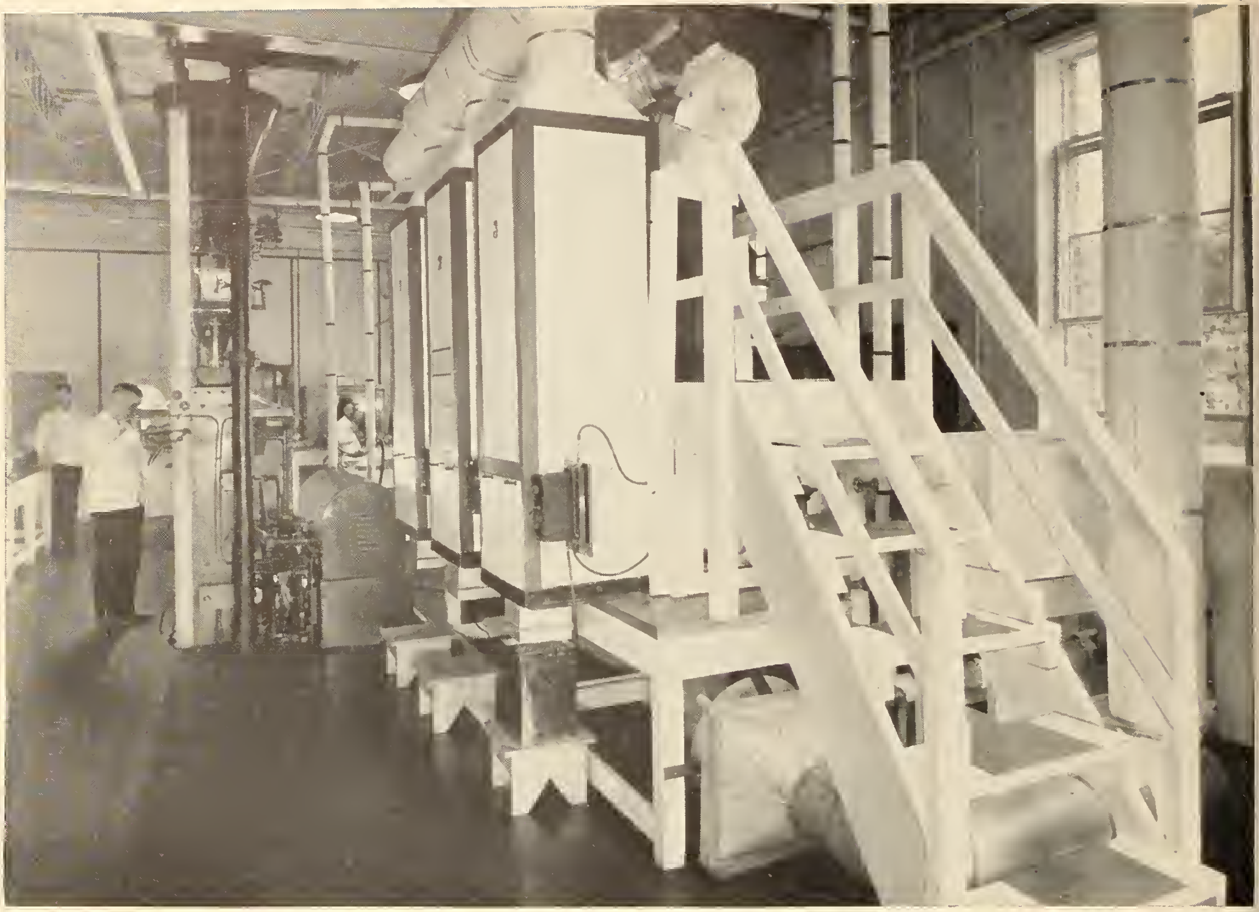

FIGURE 2.—Conditioning bins for adjusting the moisture content and temperature of dehydrated food in preparation for compression. A 40-ton food press is shown in the background.

storage life, and such a study was initiated. This study naturally called for many months of storage to make possible a significant evaluation of the effects. The investigation ended before it was possible to accumulate comprehensive data. Such information as was obtained is given in connection with the discussion of the individual products.

PROCEDURES AND EQUIPMENT

Conditioning the Food Product

Most dehydrated foods must be subjected to a conditioning process before they are ready for compression. Conditioning involves the establishment of proper moisture and temperature relations. That is, the material must be heated to a certain temperature in order to promote cohesion and sufficient plasticity to avoid significant fragmentation during compression. Also, uniform moisture distribution must be established to assure proper performance of the material during compression.

The moisture contained in dehydrated food products as they come from the commercial drier is rarely uniformly distributed. Usually the surfaces of the food pieces are at considerably lower moisture levels than the centers, and consequently the material will not compress satisfactorily. Uniform distribution of the moisture can be obtained by storage at room temperature for several days, and satisfactory homogeneity can be brought about in a relatively short time by heating the material in recirculated air under carefully controlled conditions of temperature and humidity.

Since the heat required for prompt conditioning and satisfactory compression will cause deterioration of the food on prolonged exposure, it is essential that the weight of material held in the conditioning equipment be balanced against the production capacity of the compression plant so that the food is exposed to high temperatures for as short a time as possible.

Stored dehydrated foods in which the moisture was uniformly distributed were conditioned in a short time and without noticeable impairment of organoleptic quality in a cabinet-type cross-flow drier modified to function as a conditioner by controlling the humidity so as to avoid surface drying. Weighed portions of the material were placed on the trays in wire-mesh baskets. The heating time required ranged from about 5 to 30 minutes, depending on the commodity and the conditions. The velocity of the air across the trays was approximately 500 feet per minute. In most cases the materials compressed satisfactorily after being heated for 15 minutes. In some preliminary work the material was placed in closed containers and heated in a constant-temperature laboratory oven. This procedure generally gave satisfactory results, but the circulating-air method is much more rapid and more adaptable to commercial practice. Wet- and dry-bulb temperatures applicable to the conditioning of materials that contain uniformly distributed moisture are given later in discussing the compression characteristics of specific foods.

For use in conditioning experimental batches of dehydrated materials a triple conditioning-bin unit was developed in the Beltsville laboratory (fig. 2). Each bin has a capacity of 10 cubic feet and may be operated as an individual unit with separate temperature control and recorder. The bins are connected to an air-circulating fan and hot-water heat exchangers which can be regulated to give any rate of air flow up to 4,000 cubic feet per minute and temperatures within the range of 100° to 210° F. One of these bins is equipped with a controlling and recording psychrometer which, through activation of a special steam valve inserted into the air duct, automatically controls the humidity of the air.

Designs for suitable conditioning units may vary greatly but will be considerably influenced by the commodities to be handled, the distribution of moisture in the dehydrated product, and the size of the compression plant. Conditioners designed to permit continuous instead of batch operation have been suggested. The designs are along the lines of those for tunnel driers.

Food Presses Used

Slow-Acting Presses

Some of the work was done with hand-operated hydraulic presses of the Carver laboratory type, one of which is shown in figure 3. This type of press is widely used in research work where small samples are under study. It is ordinarily operated with round steel molds ranging up to $3\frac{1}{2}$ inches in diameter. Special rectangular molds were provided for this work. Figure 3 shows such a mold fitted to the Carver press.

In early work on larger blocks an electrically powered 50-ton hydraulic press, manufactured by the Elmes Engineering Works, was used (figs. 4 and 5). These presses were slow acting and were not fitted with stripping and ejecting mechanisms. Charging the molds, performing the compression operation (in the case of the small press), stripping the mold, and removing the block were therefore manual operations and considerably slower than would be the case in commercial practice with equipment specially designed for the work. With the Elmes press the speed of ram movement during practically the entire stroke was approximately 1 inch per second. Manual ejection of the block from the mold required 12 to 15 seconds.

The molds used with these presses were of various types. In some the mold box and lower die were fixed and the upper die was movable, and in others the mold box was suspended or floating with both dies movable. In compressing egg powder special provision was made for evacuating the air from the molds, the dies being perforated and the perforations connecting with channels leading to the vacuum pump. Figure 6 shows some of the different molds

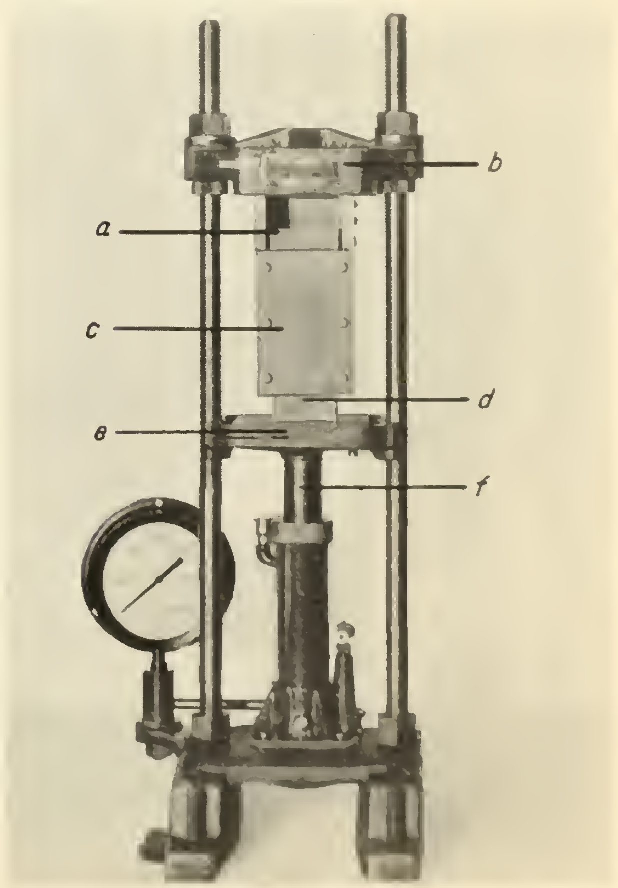

Figure 3.—A press of the type used in many of the experiments: *a*, A food block just ejected from the mold box; *b*, upper platen; *c*, mold box; *d*, lower die; *e*, lower platen; *f*, press ram.

used, and figure 7 is a line drawing of some of the details of the vacuum mold.

Mold clearances, expressed as differences in dimensions of the mold-box interiors and the die exteriors, ranged from 0.004 to 0.020 inch for the various molds used. Under the test conditions it was found desirable to maintain clearances of about 0.010 inch in order to facilitate escape of air. In compressing egg powder, vertical grooves $\frac{1}{32}$ inch wide and $\frac{1}{16}$ inch deep, spaced $\frac{3}{8}$ inch apart, were machined in the mold box interiors of certain molds to aid in the escape of air. Excessive clearances resulted in the jamming of material between the die and mold-box surfaces and tended to produce blocks with sharp extruded edges. Such jamming action is also capable of diverting considerable pressure from the block.

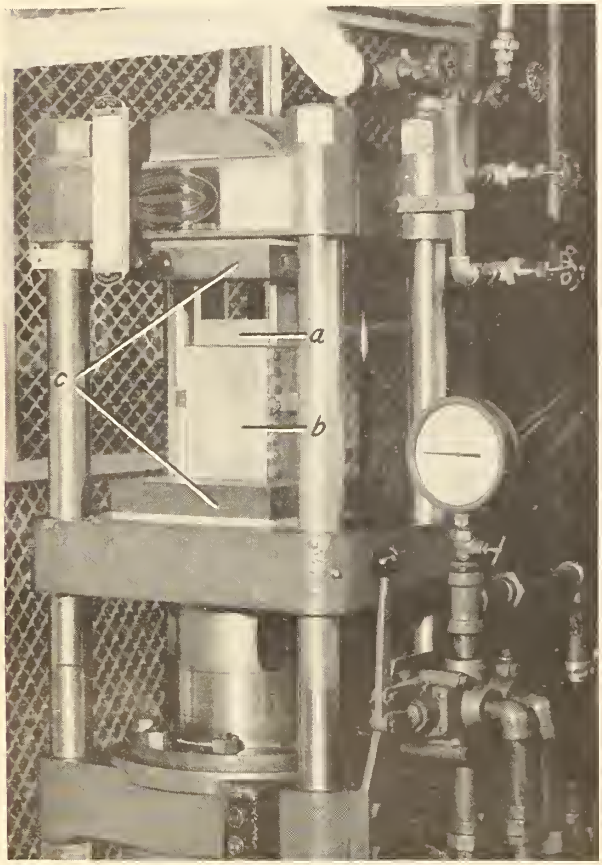

Figure 4.—A 50-ton, electrically powered hydraulic press with mold, used in some of the food-compression work. The equipment is shown in position for ejecting the block. A compressed block (*a*) can be seen emerging from the top of the mold box (*b*). The platens (*c*) are heated by circulating water.

Use of a mold box with right-angled corners and of flat-faced male dies generally results in the formation of blocks with sharp edges that tend to cut or puncture thin wrappers. Rounding the interior corners of the mold box to form a fillet of $\frac{1}{4}$-inch radius and machining a beveled $\frac{3}{16}$-inch lip on the edges of the male die faces produced blocks with partially rounded corners and greatly reduced wrapper damage.

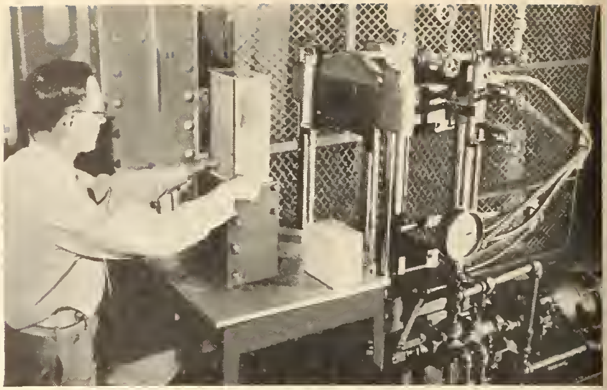

Figure 5.—The heated material is here being charged to the mold box. Next the operator will insert the moving die and place the assembled mold between the platens of the Elmes press at right.

During most of the tests the molds were maintained at the temperature to which the commodities had been heated. With cranberries, however, it was found that when the mold was cold the fruit was less likely to stick to the metal parts.

Special Food Press

Presses designed especially for experimental compression of foods became available shortly before the work ended. Manufactured by the Baldwin Southwark Division of the Baldwin Locomotive Works, they have a capacity of 40 tons. A general view of the food-compression laboratory at the Research

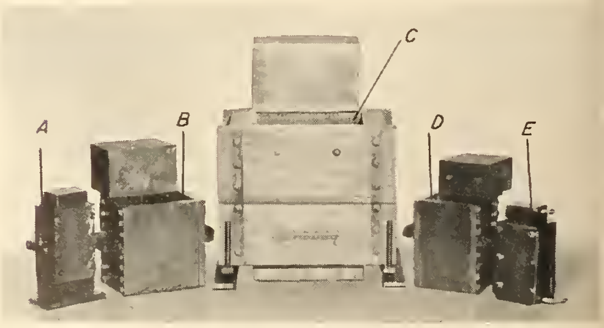

Figure 6.—Some of the experimental molds used in the compression tests. *A* and *C* are floating-type mold boxes. Grooves for facilitating escape of air during compression can be seen on interior surface of *C*. *B* and *D* are fixed-type mold boxes in which a single moving die is used. The die for each is shown resting on the upper edge of the mold box. *E* is a vacuum de-airing mold used in compressing powders. (See fig. 7.)

Center, showing one of the Baldwin Southwark presses, is given in figure 8. A close-up view of the press in operation is shown in figure 9; and figure 10, a diagrammatic sketch of the press, illustrates the principal working parts.

This press is electrically driven, may be operated semiautomatically or by hand as desired, and may be stopped at will at any stage of the compression cycle. The mold box is provided with a water jacket, and the dies contain sinuous passages through which either hot or cold water may be passed to maintain the press at any desired temperature. Accessory temperature-controlling instruments operate within a range of 70° to 200° F.

The mold box is of the floating type. At first it was believed that this type of box was essential to the formation of satisfactory blocks. The upper male die is fixed during compression, while the lower die moves upwards, and the mold box floats. This arrangement minimizes frictional effects and tends to favor uniformity of block density. The floating action is said to be essential in compressing certain ceramic materials. It was found, however, that food blocks formed in a nonfloating mold were in some instances superior to those formed with the floating arrangement.

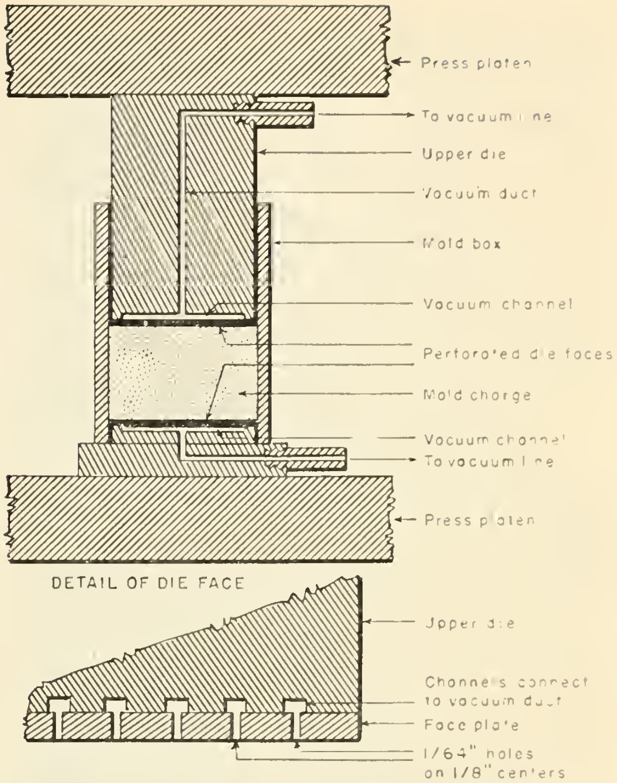

FIGURE 7. Experimental vacuum mold for compression of powdered materials.

FIGURE 8.—Interior of the food-compression laboratory at the Agricultural Research Center at Beltsville, Md., showing the special 40-ton hydraulic food press developed for the work, with the instrument panel and conditioning bins in the background. Food blocks are being weighed and wrapped at the work tables.

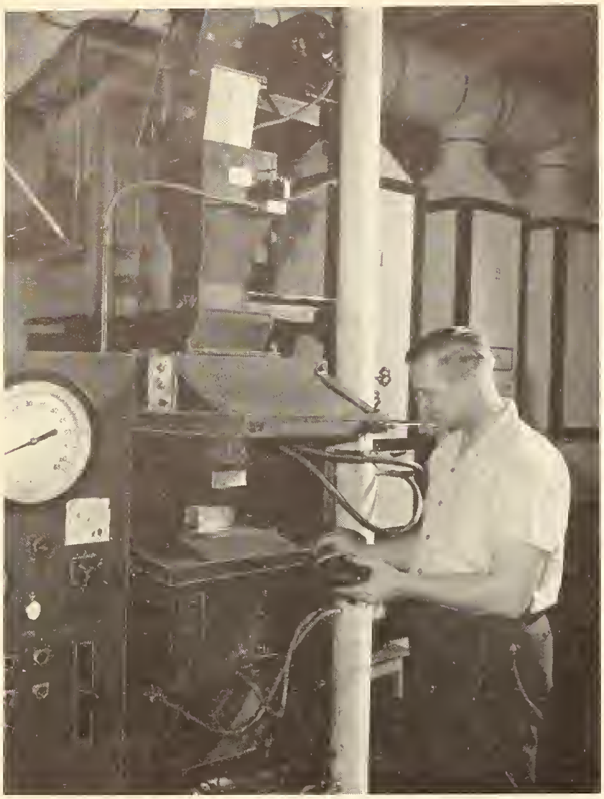

Figure 9.—Close-up view of the special food press, showing food block about to be ejected.

The food is charged to the mold through an opening in the top platen. The charging chute and upper die are fixed to a slide which is moved by hydraulic cylinders. The slide correctly places the upper die and chute in position over the mold box during charging and pressing operations. The parts are shown in the charging position in figure 10. The lower die remains up during stripping and ejecting operations. When the block is stripped, the face of the lower die is left flush with the upper edge of the mold box, and a toe plate fixed to the lower edge of the charging chute discharges the block as the slide moves to the charging position.

The press is so designed that molds of different sizes may be installed. Those used in this work produce blocks measuring approximately 4¼ by 6½ and 3 by 5 inches, of any thickness desired. The faces of the male dies are removable, which makes feasible the use of surfaces of various shapes. In some tests convex faces were used in an attempt to reduce the bulging that occurs when a tight paper wrap is used to restrain expansion during cooling, but they were found to be practically ineffective. Vertical grooves, $\frac{1}{32}$ by $\frac{1}{32}$ inch, spaced ⅞ inch apart, are machined in the interior faces of the mold box to facilitate the escape of air during compression. Speed of ram movement during practically the entire compression stroke is approximately 3 inches per second.

When in semiautomatic operation the motions of the press are controlled by solenoid valves which are energized by suitable pressure and limit switches. The press weighs the food, charges the mold, completes the compression, and discharges the food blocks at the rate of four to six per minute at zero dwell.

Charging the Molds

Bulk density was found to vary considerably for most of the uncompressed dehydrated foods that were under consideration. Thus, charging molds on a volume basis was not in general a satisfactory means of securing blocks of uniform weight. Charging the molds by weight, however, offers no serious difficulties and can usually be accomplished by means of suitable automatic weighing devices.

The position of the weighing step in the process depends considerably on the commodity and the type of conditioner employed. In the bin-type conditioner the material can be weighed only after heating, so provision must be made for weighing and transferring the material to the press without significant loss of heat. It appears possible to accomplish this satisfactorily by periodically discharging the conditioner to a

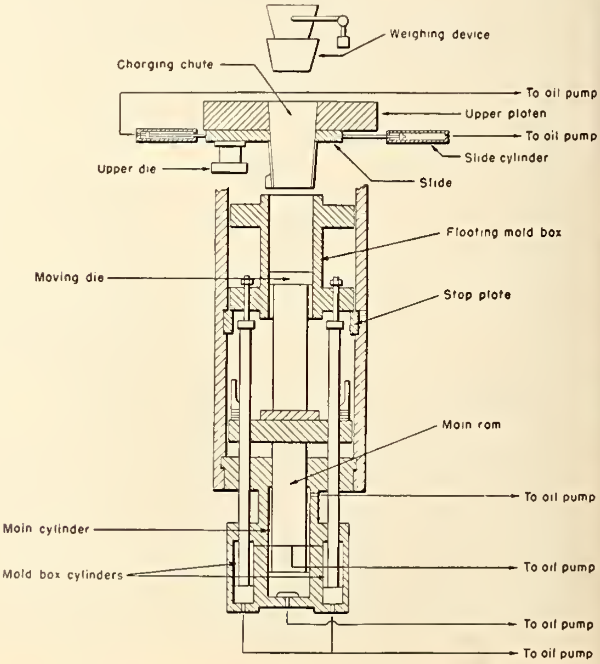

Figure 10.—Diagrammatic sketch of the 40-ton semiautomatic food press.

heat-insulated hopper which feeds an automatic weigher placed directly above the press feed chute. In a tunnel- or cabinet-type conditioner, weighing either before or after conditioning is permissible. Weighing leafy materials, such as dehydrated cabbage, before conditioning was found to be advisable. During conditioning such materials should be held in wire-mesh containers provided with covers, since the velocity of the conditioning air stream is usually sufficient to cause movement of light material.

Pressing

Although the actual compression process follows the same general pattern for the various products, some modifications and adjustments are required, depending on the character of the material. It is essential that pressing immediately follow the conditioning treatment, and in some cases it is also important that the temperature of the mold and dies be properly maintained. With a press in continuous operation there is little opportunity for serious temperature change of the molds, since the food coming directly from the conditioner serves to maintain the proper temperature level of the parts coming into contact with it. After extended shut-downs during which the press may have become cold, care should be taken to bring it to the proper operating temperature before using. It is important to note that best results are obtained when the temperatures are adapted to the particular products handled.

In the experimental work the mold box was charged with the conditioned product, the press was closed, and the pressure was raised to the selected maximum as quickly as possible. The nip period was usually about 2 to 10 seconds, depending on the equipment, the material, and the size of the block. The pressure was maintained at the maximum level for the selected length of time (dwell) and then released, and the block was ejected as quickly as possible. The required post-compression treatment followed immediately.

It is to be noted that procedures can be varied somewhat. For example, a given dwell at one pressure may give results substantially identical with those obtained with a shorter dwell at a higher pressure. Within the range of satisfactory compression temperatures at a given moisture level, somewhat lower pressures are generally required at higher temperatures. Variations in characteristics of products sometimes necessitate modification of compression practices.

A recently developed rotary press is reported to permit high production rate with fairly long dwells. The use of multiple-cavity molds also offers a possible solution to capacity problems when fairly long dwells are employed. However, from the standpoint of production capacity, long dwells are usually impracticable in commercial operation with conventional equipment. When equipment of a satisfactory type is used, long dwells are generally not necessary for attainment of acceptable results if other compression and post-compression procedures are properly selected. It is possible that shorter dwells than those noted herein may be permissible for certain products. Limitations of the equipment available during work on cereal products and some fruit products made the use of very short dwells inadvisable.

Moisture content often critically affects the compression characteristics of a material. At lower moisture levels, lower block densities are usually obtained at a given pressure, and cohesive quality may be considerably lower. The temperature required for satisfactory compression generally decreases as the moisture level rises. Temperature conditions, especially as they influence breakage and production of fines, become more important as the moisture level falls. At very low moisture levels many dehydrated foods do not yield satisfactorily coherent blocks at any temperature. In the majority of cases the procedures adopted apply to the specific commodities at moisture levels conforming to United States Quartermaster Corps specifications in force at the time the tests were conducted.

Post-Compression Treatment

Under pressure in the press, food blocks attain a maximum density which they usually do not retain. Immediately after pressure is released an initial rebound or very rapid expansion occurs in a direction counter to the original movement of the male dies. When blocks were measured in the press under pressure and again immediately after ejection it was common to find that immediate rebound had resulted in a 30-percent increase in block height. After ejection most compressed products continue to expand while warm at a comparatively slow rate. This latter expansion may result in a serious decrease in the cohesive quality of the block as well as in the density if some form of restraint is not employed. The tendency to expand after ejection usually decreases as dwell is increased. Sometimes when restraint is not used the block continues to expand until it falls apart.

Holding presses, or in certain cases simple wrapping, may be used to prevent post-ejection expansion. It is necessary to keep vegetable blocks under restraint only until they have cooled to a temperature at which pliability becomes negligible. The restraining pressure required is usually less than 10 pounds per square

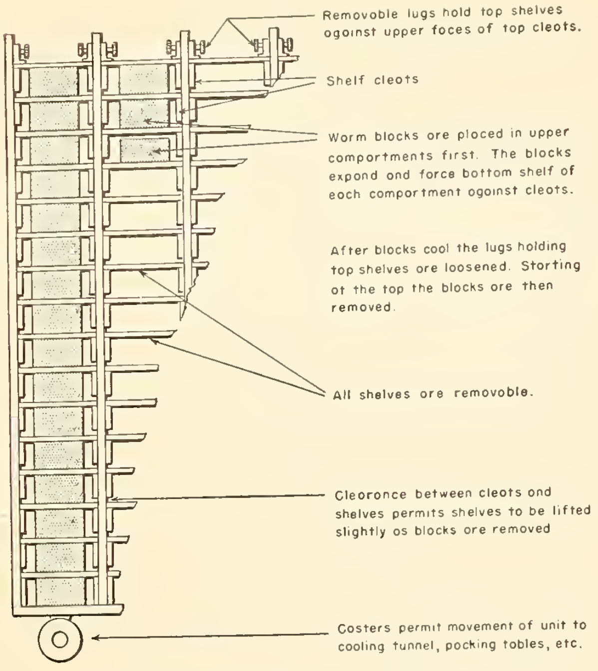

Figure 11.—Details of food-block holding press.

inch. Therefore the holding presses may be light in weight and inexpensive.

In one proposed form of holding press (fig. 11) a series of individual rectangular compartments is housed in a vertical wooden frame. The compartments are open at two ends and are slightly greater in height than the ejected blocks. The openings may be considerably larger than the blocks in width and length, as expansion is restricted mainly to an increase in block height, or thickness. Members forming the top surfaces of each bank of compartments are held in place by latch mechanisims or adjustable lugs. The compartments may be shimmed if blocks differing in final height are desired. After ejection from the press the blocks are placed as quickly as possible in the holding-press compartments. They expand slightly until restricted by the upper and lower compartment surfaces. When the blocks have cooled sufficiently the upper member of each bank is loosened and the blocks are removed. Small holding presses of this type were found to give good results.

It appears possible to construct holding presses capable of carrying out the required holding operations automatically. A design incorporating two horizontal conveyor loops, formed with roller-type chain, placed one above the other, is one possibility. Rigid cross members attached to the outer surfaces of the traveling chains can act as the restraining surfaces (fig. 12). In this type of holding press the ejected block would be placed on the open section of the lower conveyor at A. The block would move into the press and be restrained by the rigid cross members attached to the upper and lower traveling loops. The speed of travel should be sufficient to insure cooling of the blocks in moving from A to B.

Cooling of blocks in holding presses can be accelerated through the use of forced convection. To demonstrate this point, cooling tests were conducted on 1-pound blocks of diced carrots, 3 by 5 by approximately 1¾ inches, with densities of 60 pounds per cubic foot; the moisture content was 5.2 percent. The blocks were cooled from an initial temperature of 160° F. to a final center temperature of 90° F. while confined in a wooden holding press exposing the narrow sides and ends only. With forced convection (air velocity 600 feet per minute, air temperature 76° F.) unwrapped blocks cooled to 90° F. in 50 minutes, whereas cellophane-wrapped blocks required 140 minutes. Cooling under identical conditions but with natural convection required 160 minutes for unwrapped blocks and 205 minutes for cellophane-wrapped blocks (fig. 13).

Tests were conducted on the cooling of blocks identical with those described above while restrained between water-cooled metal platens (fig. 14). With natural convection combined with platen cooling, unwrapped and wrapped blocks cooled to 90° F. in about 65 minutes at an ambient temperature of 70°. Unwrapped blocks and cellophane-wrapped blocks cooled from 160° to 90° in 30 and 60 minutes respectively when forced-convection cooling (air

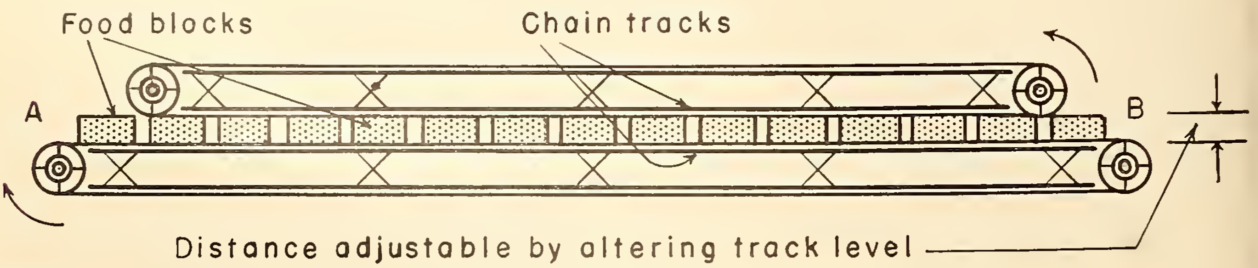

Figure 12.—Design of a holding press incorporating two horizontal conveyor loops, with rigid cross members attached to the outer surfaces of the traveling chains to act as the restraining surfaces.

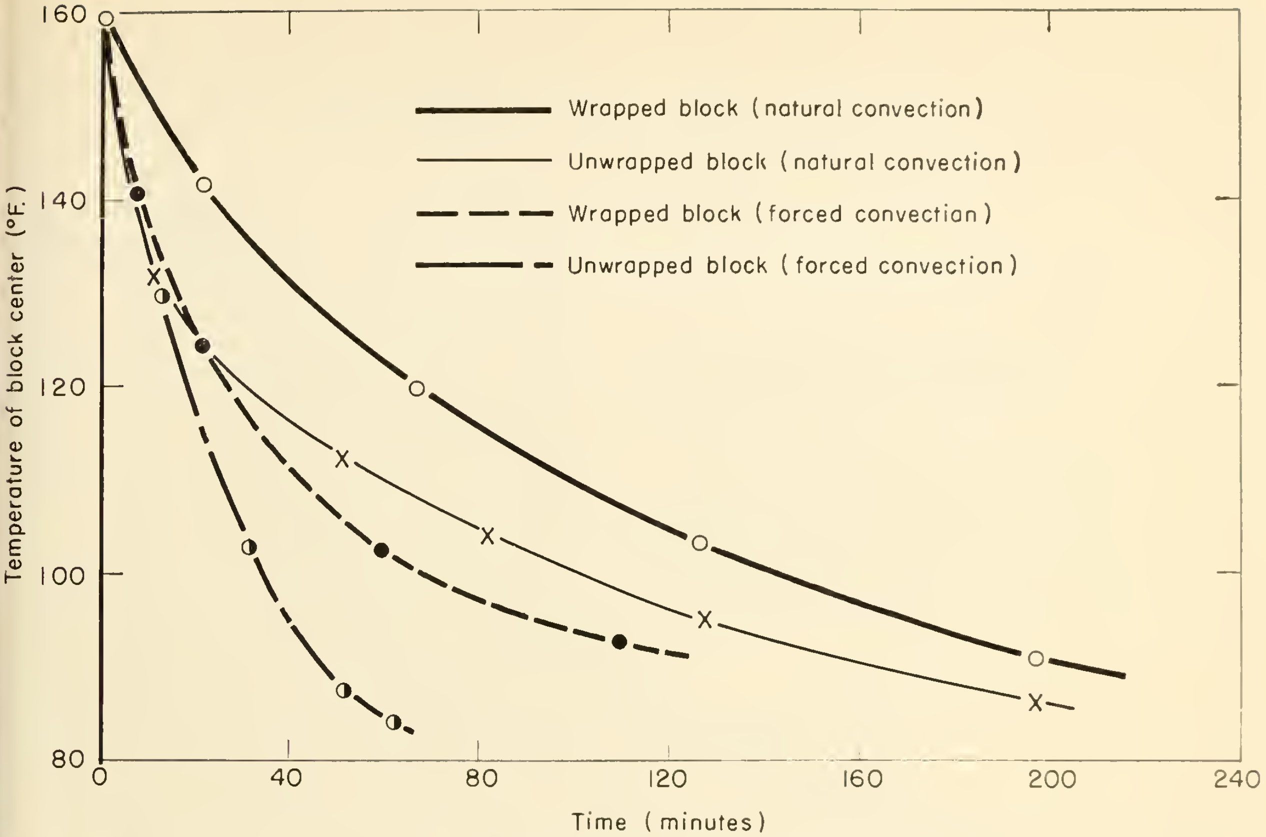

Figure 13.—Time required for cooling carrot blocks in wooden holding presses from an initial center temperature of 160° F. to 90° F.

velocity 600 feet per minute) combined with platen cooling was employed at an ambient temperature of 70°. These tests indicate that the holding-press requirements for a given plant capacity can be materially reduced through the use of specially designed, metal holding presses.

Cooling curves for 1-pound, 3- by 5- by approximately 1¾-inch blocks of diced carrots enclosed in paperboard cartons are shown in figure 15. In this series of tests the blocks were initially at 160° F. Block density was maintained at 62 pounds per cubic foot. The cartoned blocks were cooled to a center temperature of 90° F. under natural and forced-convection conditions while restrained (1) in a wooden holding press, (2) between water-cooled steel platens, and (3) solely by the enclosing carton. The carton was 0.013 inch thick. The temperature of the cooling air and the water-cooled platens was 76° F. In cooling under forced convection, the 5- by 1¾-inch block surface faced the air stream. The cooling curves shown for the various conditions indicate that the use of cold platens is advisable if the cooling time for cartoned blocks is not to exceed 130 minutes. Cooling of the unrestrained cartoned blocks was desirably rapid under forced convection, but the practice is not recommended since it was found that the restraining effect of the carton alone is not sufficient to prevent bulging of the compression faces of the blocks.

The duration of exposure to elevated temperatures involved in cooling, as noted above, is not nearly as great as that frequently occurring in routine dehydration processes. A case in point is the common practice of finish-drying foods with a low moisture content in bins for several hours at temperatures comparable to those used during compression.

As a general rule, the cooling time should be kept as short as possible. The practice of immediately packing hot blocks in large cans and stacking the cans closely will undoubtedly result in a very slow dissipation of heat and a consequent deterioration in quality and should be carefully avoided.

Wrapping blocks before restraining them is sometimes desirable. Because heated material is pliable the edges of heated blocks are usually not as sharp as those of cold blocks and are not as likely to cut wrappers. The use of wrappers as the sole means of post-compression restraint was tested with beets, onions, apple nuggets, etc., with varying degrees of success. Blocks frequently differed in density, owing to variations in tightness of wrap. The wrapped blocks usually had at least slightly bulged surfaces because of insufficient restraint at surface centers. Uniform results were particularly difficult to obtain with very short dwells. It appears advisable to restrain wrapped blocks in holding presses until cool if very uniform results are desired. Wrapping immediately after compression sometimes improves the final cohesive quality of vegetable and fruit blocks, but compressed egg-powder blocks require no post-compression restraint.

Apricots, peaches, and prunes are generally compressed at room temperature and should be restrained until packed in rigid containers, as they show almost the same expansion tendency after being restrained for several hours as when first compressed. Blocks of whole cranberries have a somewhat similar tendency to expand when cool. Cranberries are compressed after heating; the blocks retain their shape reasonably well if they are cooled in a holding press and then tightly wrapped.

Drying Compressed Blocks

Commodities were not generally compressed at moisture contents above specification limits, since drying after compression necessitates the use of additional equipment and materially increases cost. It was found advisable, however, to compress experimentally two commodities—potatoes and egg powder—at moisture contents higher than required by the specifications.

Compressing dehydrated potatoes at specification moisture levels results in excessive fines, even when the material is conditioned at relatively high temperatures. Compression at higher moisture levels with later drying of the blocks therefore appears to be the only way to obtain a satisfactory product. The compression of egg powder containing not in excess of 2 percent of moisture—the limit now being sought—is likewise attended with difficulties. The cohesive qualities of this product are such that a satisfactory block cannot be made with reasonable pressure. The solution of this problem appears to be either compression at the 5-percent moisture level and later drying of the blocks, or compression in the final container.

Potato blocks were dried experimentally in a vacuum shelf drier, a cabinet drier, a drier employing heated air that pulsated between atmospheric and superatmospheric pressures, and also by means of a

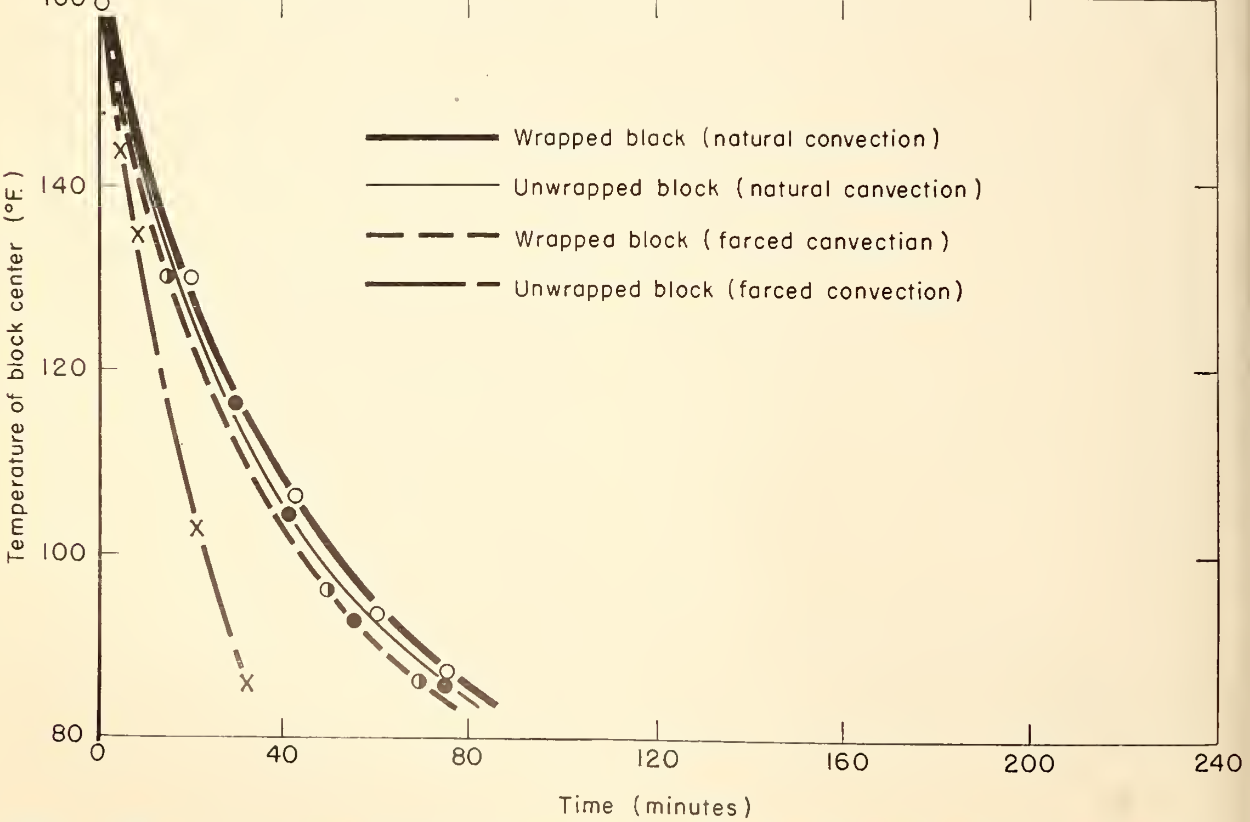

Figure 14.—Time required for cooling carrot blocks between water-cooled metal platens from an initial center temperature of 160° to 90° F., with an ambient temperature of 70°.

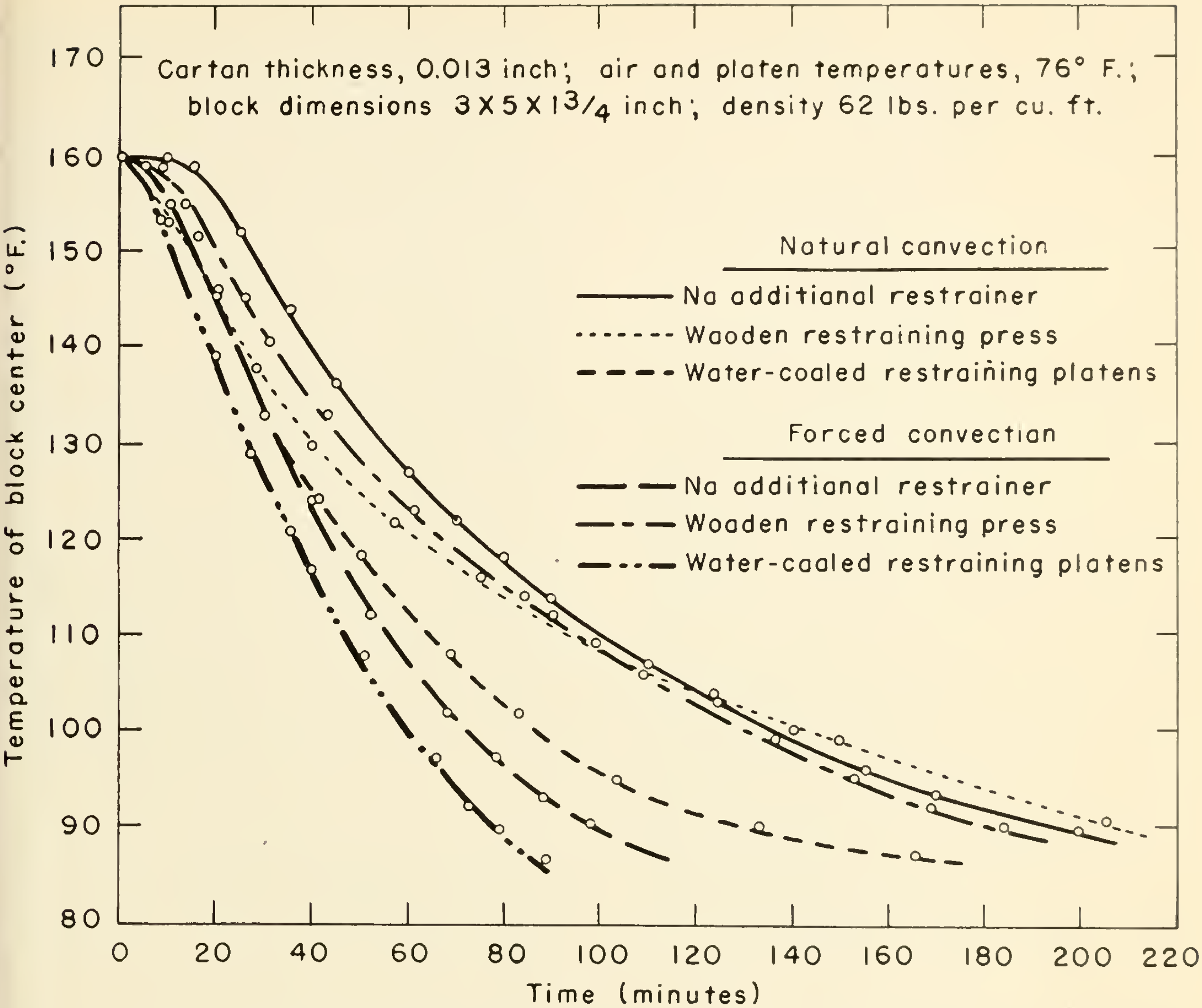

FIGURE 15.—Time required for cooling 1-pound blocks of compressed carrots in paperboard cartons, under natural and forced convection and different restraining conditions, from 160° to 90° F. or lower.

procedure involving high-frequency heating in a vacuum. Egg-powder blocks were dried experimentally in a vacuum shelf drier.

Summarized results of tests using the various drying methods are given under the descriptions of compression procedures for these two commodities.

REHYDRATION AND EVALUATION OF THE COMPRESSED PRODUCT

In judging whether the food block was satisfactory, determining acceptable methods for reconstitution of the dehydrated and compressed products, and testing their organoleptic qualities, the procedures varied, of course, with the different commodities. There were also a few minor variations in procedure in the different laboratories where the work was done, but the following examples will illustrate the essential nature of this branch of the work.

Physical Character of the Block

The food blocks were graded "good," "fair," and "poor." The factors considered in grading blocks of sweetpotatoes are given as an example:

Grade and factor:	
Good:	*Description*
Shape	Symmetrical, free from bulges.
Cracking	Block solid, no cracks.
Surface	Smooth, pieces firmly pressed together.
Fragmentation	Pieces whole, no crushing.
Crumbling	Block remains intact when handled, no pieces falling out.
Melting	Free from "cooked" or "melted" appearance, pieces not fused together.
Discoloration	Free from dark streaks or foreign matter.

Grade and factor:	*Description*
Fair:	
Shape	Fairly good, only slight bulging.
Cracking	Only slight.
Surface	Fairly smooth.
Fragmentation	Only slight.
Crumbling	Only slight and from the surface, few pieces falling out.
Melting	Free from melted appearance.
Discoloration	Few dark streaks only, free from excessive foreign matter.
Poor:	
Shape	Badly misshapen or "sprung," badly bulged.
Cracking	Wide cracks, fragile, easily broken up with handling.
Surface	Rough, pieces projecting, buckling.
Fragmentation	Pieces badly crushed.
Crumbling	Cubes and pieces drop off easily with very little handling.
Melting	Melted appearance on surface, cubes fused together.
Discoloration	Excess of dark streaks or foreign matter.

Rehydration

Rehydration tests were made on blocks of sweetpotatoes 24 hours or more after compression, and the following methods were studied to determine the rate of water uptake in each. Water was used in the proportion of 6 parts to 1 of potato, by weight. The rehydration ratio was calculated from the weight of the reconstituted product divided by the weight of the dehydrated product. The rate of water uptake was determined by removing the basket containing the sample from the water, allowing the sample to drain for 30 seconds, and then weighing it. This was repeated at 10-minute intervals until no more water was absorbed. The rate of rehydration was taken as the gain in weight per 100 grams of material in 1 minute.

HOT-SOAK METHOD.—The block was placed in a wire basket and lowered into boiling water in a double boiler heated over boiling water, and the boiling was continued until no more water was absorbed. A variation of this procedure consisted in soaking the block in water maintained at 200° F. until disintegration was complete and then raising the temperature to boiling.

COLD-SOAK METHOD.—The block was put into the water at room temperature and allowed to soak without heating until it fell apart. The material was then heated over boiling water until it no longer absorbed water.

ASCENDING-TEMPERATURE METHOD.—The block of sweetpotatoes was put into water at room temperature and then was placed immediately over boiling water and heated until no more water was absorbed.

DESCENDING-TEMPERATURE METHOD.—The block was put directly into boiling water, which was allowed to cool to room temperature. When the block had fallen apart, the sweetpotato was placed over boiling water and heated until it no longer gained weight.

For compressed sweetpotato, the hot-soak method gave the best combination of rehydration ratio and rate of rehydration. Although the sweetpotatoes absorbed slightly more water by some of the other methods, the hot-soak method required the least time and was considered the most practical.

Organoleptic Quality

Uncompressed samples were used as controls in evaluating the organoleptic qualities of the compressed products. The control samples were taken, of course, from the same lot from which the compressed products were prepared; they were usually of such quality as to conform to Army specifications. The uncompressed samples were rehydrated and cooked according to conventional procedures—that is, in most cases the material was subjected to a preliminary soak in cool water and then boiled until tender. Soaking dehydrated foods in cool water in some instances tends to produce a product of higher quality than is obtained through the immediate use of hot or boiling water (*1*, *7*). For that reason the controls may have had some advantage over the compressed products in those cases where hot water was required to disintegrate the blocks. (Procedures for disintegrating and cooking compressed materials are discussed later under specific commodities.) In cooking a given commodity, the water-to-solids ratio was held constant for compressed and uncompressed samples. The water-to-solids ratios generally used for various commodities and the soaking and cooking times for uncompressed samples are give in table 1.

TABLE 1.—*Data pertaining to reconstitution of control samples*

Commodity	Water-to-solids ratio	Soaking time	Boiling time
	Parts by weight	*Minutes*	*Minutes*
Apple nuggets	8⅓ to 1	0	30
Beets	12½ to 1	60	15
Cabbage	12½ to 1	60	15
Carrots	14 to 1	60	15
Cheese-soya soup	7½ to 1	....	30
Cranberries	12 to 1	0	14
Onions	12½ to 1	60	30
Pea-soya soup	7½ to 1	....	30
Potatoes	8⅓ to 1	60	15
Rutabagas	14½ to 1	60	15
Sweetpotatoes	8 to 1 6 to 1	60	10

A panel of five or more judges trained to recognize the various organoleptic qualities in dehydrated foods scored the samples. The score sheets provided space for rating, color, flavor, taste, and texture. In some instances scoring was on the basis of "excellent," "good," "fair," and "poor." In others, the values ranged from 5.0 to 1.0 in intervals of 0.5, with 5.0 indicating a product equal to the fresh equivalent and 1.0 an inedible product.

The effects of compression and storage on color were measured by one or more of the following methods: (1) By comparing the color of the reconstituted food with the control sample; (2) by matching the color of the reconstituted sample with Munsell color chips: (3) by measuring the color of the cooking liquid with a colorimeter.

RESULTS OF COMPRESSION STUDIES ON SPECIFIC DEHYDRATED VEGETABLES

Brief summaries of the results of compression studies on dehydrated beets, cabbage, carrots, onions, potatoes, rutabagas, and sweetpotatoes follow. For most of these commodities the reductions in volume under different compression conditions are not considered here. The volume reductions attainable are given in summarized form in table 18 (p. 44).

Beets

Beets containing moisture ranging from 3.5 to 5.5 percent were satisfactorily compressed after being conditioned at 140° to 160° F. Blocks of good cohesive quality were obtained under a wide range of compression conditions. Typical compression data for dried beets are given in table 2.

Compression conditions required for diced, sliced, and stripped beets of equal moisture content were found to be practically identical. From the standpoint of density and cohesiveness of block, the results obtained were approximately the same regardless of the form of the material.

The maximum density attained by blocks while under pressure in the press, or the so-called mold density, varied only slightly for widely different conditions of pressure and dwell. With diced and stripped material the mold density ranged from 89 to 95 pounds per cubic foot. Block densities were considerably lower immediately after ejection, and the decrease was always due principally to an increase in the block dimension which is taken parallel to the axis of compression. After this very rapid expansion, or rebound, the blocks continue to expand while warm, though at a much slower rate.

The preferred compression procedure for diced and stripped beets consists in heating the material for 20 minutes in an air stream (t_d, 150° F.; t_w, 91° F.: air velocity, approximately 500 feet per minute) and compressing at a pressure of approximately 1,200 pounds per square inch with from 0 to 3 seconds of dwell. The density of the finished block ranges from approximately 50 to 65 pounds per cubic foot depending on the dwell, the material, and the press. Variation of dwell and the use of holding presses to restrict expansion make feasible the formation of blocks with any density desired in the range of 55 to

Table 2.—*Test conditions under which dehydrated diced beets were compressed*

Press used	Pressure	Temperature	Moisture content	Dwell	Cooling conditions	Final density [1]	Cohesive quality
	Pounds per square inch	*°F.*	*Percent*	*Seconds*		*Pounds per cubic foot*	
Carver	650	122	4.1	60	Unrestrained	52	Fair.
Do	450	122	4.1	60	do	42	Do.
Do	650	140	4.1	60	do	62	Good.
Do	650	160	4.1	60	do	64	Do.
Do	850	160	4.1	60	do	67	Do.
Elmes	900	155	4.1	3	Holding press	61	Fair.
Do	1,100	155	4.1	3	do	61	Good.
Do	1,100	155	4.1	3	Unrestrained	51	Fair.
Do	1,500	155	4.1	3	Holding press	67	Good
Baldwin Southwark	1,200	150	4.6	3	Unrestrained	65	Do
Do	1,200	150	4.6	2	do	63	Do
Do	1,200	150	4.6	0	do	57	Fair.
Do	1,200	150	4.6	0	do	56	Do.
Do	2,400	150	4.6	0	do	61	Do.
Do	1,200	150	5.5	0	do	55	Do.
Do	1,200	150	5.5	0	Holding press	75	Good.
Do	1,200	150	5.5	3	do	77	Do.

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[1] 24 hours after cooling to room temperature. Density of the diced materials before compression ranged from 22 to 25 pounds per cubic foot.

75 pounds per cubic foot. Maintenance of the mold box and male dies at 150° F. is advisable. Slight loosening and fragmentation of surface pieces result when these parts are at room temperature.

Block surfaces may bulge slightly and surface pieces may occasionally curl slightly outward when blocks are compressed with zero dwell and not restrained while cooling. Failure to restrain expansion gives rise to another problem, since slight variations in the conditions of compression and in the material being compressed have a considerable effect on the density of the finished block. However, as previously stated, this difficulty does not arise if the blocks are restrained in suitable holding presses.

Paper wraps and cartons do not restrain expansion satisfactorily. The compression faces of blocks wrapped in paper bulge slightly, and the block density varies considerably, since the extent of expansion depends on the tightness of the wrapper. Cartons are unsatisfactory because they retard the rate of cooling and do not prevent bulging.

As previously mentioned, the block expands mainly in a direction counter to the compression motion; that is, block height or thickness tends to increase while the change in block width and length is relatively small. For example, comparison of mold dimensions and dimensions of cooled blocks shows that the total linear expansion of block width and length ranges from 2 to 5 percent and depends mainly on the post-compression treatment and to a lesser degree on the pressure and dwell employed. On the other hand, the expansion of block height, or thickness, based on minimum thickness of block when under pressure in the mold compared with final thickness, was generally about 60 percent when compression was carried out at 1,200 pounds per square inch with zero dwell and the block was allowed to expand freely after ejection.

Curves indicating the rate of expansion of blocks during cooling are given in figure 16. These pertain to 1⅓-pound blocks of diced beets compressed in a 3- by 5-inch mold under the conditions indicated, and subsequently permitted to expand in still air at room temperature. Block density is plotted against age (length of time after ejection). It will be seen from these curves that under the imposed conditions expansion almost ceases after 10 minutes, and that changing dwell from 0 to 3 seconds is considerably more effective in securing a higher final block density than a twofold increase in pressure. These curves also indicate the maximum delay permissible in restraining blocks to a desired density. For example, assume that a compartment-type holding press is to be used to restrict expansion, that a block density of 65 pounds per cubic foot is desired, and that compression is carried out at 1,200 pounds per square inch with zero dwell. Then from the appropriate curve it is seen that the block must be inserted in the holding compartment within 15 seconds after ejection.

Blocks soaked in water at room temperature took several hours to disintegrate. Using water at 200° F., however, reduced disintegration time to a matter of minutes. Typical results for the latter procedure are given in table 3. These results apply to diced material containing approximately 5 percent moisture, compressed in a 3- by 5-inch mold.

Table 3.—*Time required for disintegration of diced beet blocks of different weight, thickness, and density, by the hot-soak method*

Material	Approximate block weight	Block thickness	Block density	Time required for disintegration [1]
	Pounds	*Centimeters*	*Pounds per cubic foot*	*Minutes*
Lot C 106 R	1⅓	7.1	57	7
Do	1⅓	6.4	65	26
Do	1⅓	5.5	75	60
Do	1	4.5	70	26
Do	1	4.5	70	24
Do	½	2.2	72	15
Do	¼	1.1	72	14
Lot C 109 R	1	4.0	76	19
Do	½	2.1	75	10
Do	¼	1.0	77	6
Do	⅛	.6	73	2½

[1] 1 part of beets to 12 parts of water by weight; temperature maintained at 200° F.

These results, particularly those that pertain to lot C 109 R, show that the time required for disintegration is approximately proportional to block thickness. The disintegration time of 60 minutes required for the block with a density of 75 pounds per cubic foot is considered excessive; such prolonged treatment results in undesirable leaching, which has a deleterious effect on flavor and color. It will be observed that blocks prepared from C 109 R disintegrated in approximately two-thirds the time required for comparable blocks of C 106 R. This apparently was due to inherent differences in the two lots of beets, which were purchased from commercial dehydrators in widely separated growing areas.

There was no visual evidence of damage to the dehydrated material when compression was carried out at temperatures of 140° to 160° F. Tests showed

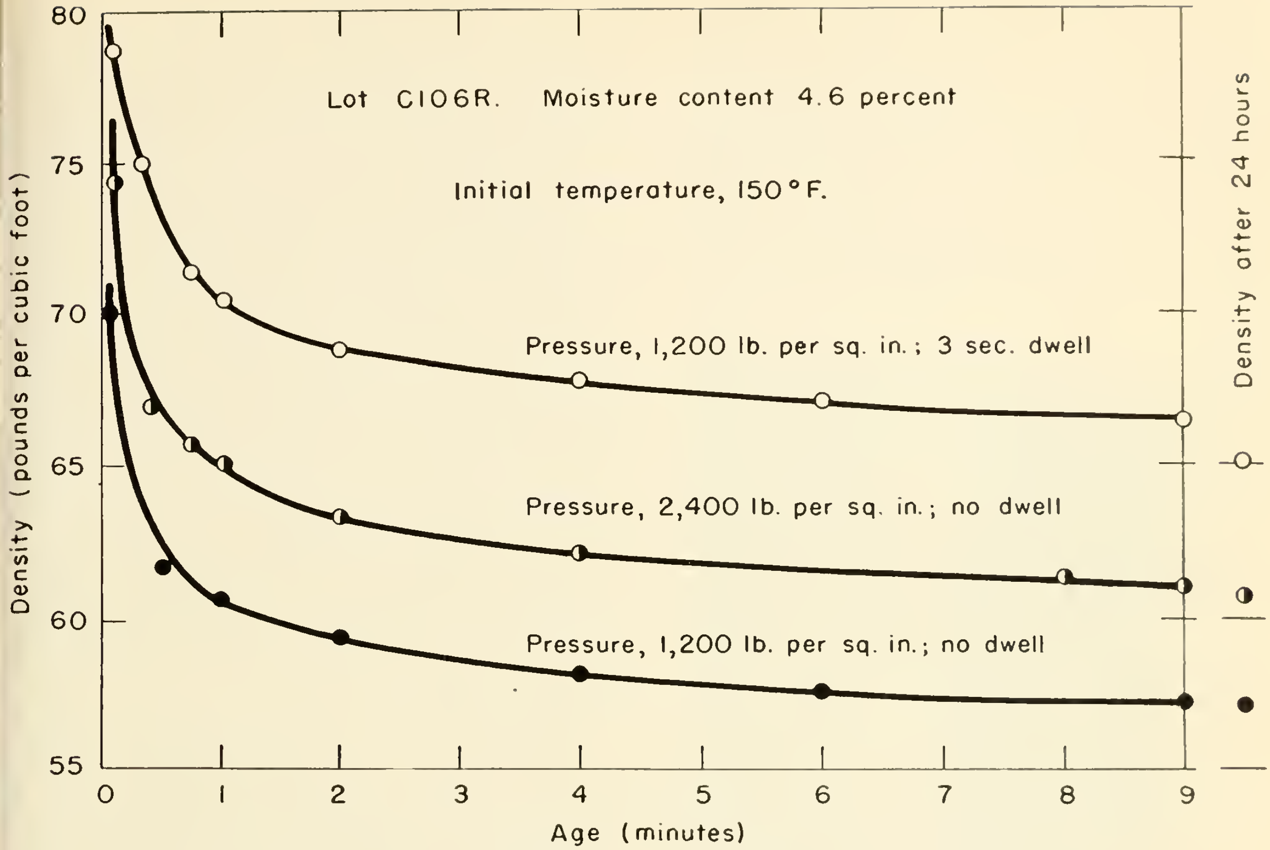

Figure 16. Rate of expansion of blocks of compressed beets during cooling.

that the production of fines in this temperature range is practically zero for compression at pressures of 250 to 2,400 pounds per square inch. With compression at 122° F. the production of fines varied from 0.5 to 1.8 percent for material at the 4-percent moisture level, but no relationship between fines and pressure was evident. Compression at room temperature resulted in a high percentage of fines.

Organoleptic tests conducted on this commodity involved 1-pound blocks of diced material. The material was heated to temperatures of 150° to 160° F. and was compressed at pressures ranging from 650 to 1,200 pounds per square inch with dwells of 30 seconds to zero. Moisture contents ranged from 4 to 5 percent and block densities from 60 to 75 pounds per cubic foot. Results of the organoleptic tests showed that the compressed material is indistinguishable from the uncompressed, provided suitable reconstitution procedures are applied. In evaluating the products the uncompressed control samples were soaked in cool water for 1 hour and boiled for approximately 15 minutes, whereas the blocks were treated by various procedures.

When the blocks were disintegrated according to the hot-soak method it was found advisable to limit block densities to such values as would permit complete disintegration in 25 minutes or less. Results obtained with this method were generally acceptable, but in some instances the compressed material was rated slightly lower than the uncompressed. Such differences appeared to be entirely due to inadequate soaking prior to boiling. Soaking for 5 or 10 minutes before boiling would probably improve the quality of the rehydrated product.

The best results were obtained when the dry block was separated into small clusters of dice by twisting it in the hands. The pieces were then soaked in cool water and cooked in exactly the same way as the uncompressed control material. The scores assigned to the control and the compressed products showed no significant differences in color, flavor, taste, texture, or appearance. In applying this procedure it is advisable to avoid block densities higher than about 65 pounds per cubic foot, since block cohesiveness at higher densities makes hand disintegration slightly difficult.

CABBAGE

Shredded cabbage containing 3.5 percent moisture was compressed at temperatures ranging from 140° to

160° F. Satisfactory blocks with final densities of 52 to 62 pounds per cubic foot were obtained when compression was carried out at 200 to 800 pounds per square inch with material at 140° F. (fig. 17). At 160° F., with pressures of 200 to 800 pounds per square inch, the density of the cooled blocks ranged from 55 to 70 pounds per cubic foot. In these particular cases dwell at maximum pressure was 60 seconds and expansion was restrained as quickly as possible after ejection.

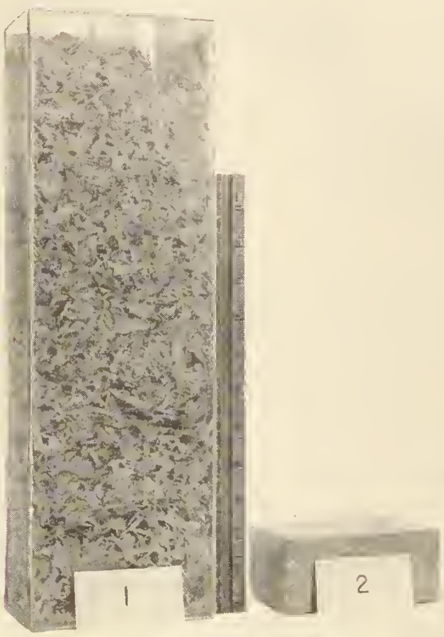

Figure 17.—Equal weights of uncompressed and compressed dehydrated cabbage. The loose material in the transparent container (1) has a bulk density of 7.5 pounds per cubic foot, whereas the compressed 1-pound block (2) has a density of 60 pounds per cubic foot. The volume reduction in this case is 87 percent.

The blocks have a pronounced tendency to expand rapidly while warm, and for this reason it is advisable to use a press that provides for rapid ejection of blocks after pressure is released. Holding presses are essential in cooling the blocks. When cooled to room temperature the blocks are satisfactorily cohesive and have no significant tendency to expand.

Preparation for compression of the material containing 3.5 percent moisture was best carried out by weighing at room temperature and then heating for one-half hour in a slightly humidified air stream (t_d, 150° F.; t_w, 95° F.; air velocity, approximately 600 feet per minute). This procedure resulted in a heated product of unchanged moisture content.

Very satisfactory 1-pound blocks at the 3.5-percent moisture level were produced at rapid rates by the Baldwin Southwark press. The material and press were heated to 150° F. Densities of the material in the mold ranged from 91 to 98 pounds per cubic foot for a wide range of pressures and dwells. Compartment-type holding presses were used to restrict post-ejection expansion, the distance between the two restraining surfaces of these presses being set so as to stop expansion when block density reached 60 pounds per cubic foot. With compression at 5,500 pounds per square inch and zero dwell it was necessary to place the block in the holding press within 3 seconds after ejection; otherwise expansion was too great to permit insertion in the holding compartments. With a pressure of 2,250 pounds per square inch and a dwell of 15 seconds the blocks expanded to the 60-pounds-per-cubic-foot density in 20 seconds. The expansion time for the same density was 3 seconds when the material was compressed for 3 seconds at 2,250 pounds per square inch. Expansion of block length and width, based on dimensions of mold and final block, was approximately 2.6 percent.

Heating to 150° and compressing with 3 seconds of dwell constituted the most practical of the procedures tested. One-pound blocks (approximately 3 by 5 by 2 inches) with a density of 60 pounds per cubic foot disintegrated in 18 minutes when immersed in water at 200° F.; disintegration took over 24 hours in water at 70° F. The blocks can be readily cleaved into thin sections in planes at right angles to the axis of compression. Sections ¼-inch thick disintegrated in 1 hour in water at 70° F.

There was no visual evidence of fracturing or other damage to the cabbage shreds when the material was heated and compressed according to the procedures here described. Cooked samples of compressed and uncompressed material were evaluated from the standpoint of organoleptic quality. The uncompressed control samples were soaked in water at room temperature for 1 hour and boiled for 10 minutes. Compressed blocks with densities of 60 pounds per cubic foot were immersed in water at 200° F. until they had completely disintegrated—approximately 18 minutes—and were then boiled for 10 minutes. Flavor, taste, texture, and appearance of the cooked materials received scores ranging from "excellent" to "good," and the compressed material was judged to be indistinguishable from the uncompressed.

Carrots

Compression conditions required for sliced, stripped, and diced carrots were practically identical, and results were generally similar for the three forms.

Heating material at the specification moisture level to temperatures in the range of 150° to 160° F. was necessary in order to obtain satisfactory results. With 60 seconds of dwell, carrots with moisture contents ranging from 4.8 to 5.2 percent, as determined by the 16-hour, 70° C., vacuum-oven method,[4] in general gave the following results when compressed in the Carver press: At a temperature of 160° F. and a pressure of 650 pounds per square inch, cohesion was good and the initial density of the ejected block was about 57 pounds per cubic foot. When cooled without restraint the block density decreased to a final value of about 54 pounds per cubic foot. The corresponding densities were about 10 pounds per cubic foot greater when compression was carried out at a pressure of 1,350 pounds per square inch. The densities after ejection were highest at a given pressure for the materials of higher moisture content.

Compression tests were also conducted on stripped carrots containing 3.7 percent moisture under the same conditions. This low moisture content resulted in blocks of poorer cohesive quality and lower density. For example, blocks compressed at 650 pounds per square inch were of only fair cohesive quality and the initial density of the ejected block was only 49 pounds per cubic foot.

Tests with the Baldwin Southwark press showed that satisfactory blocks of diced dehydrated carrots can be formed by rapid compression procedures. The moisture content of the materials used ranged from 4.5 to 4.8 percent. Compression can be accomplished with zero dwell, but the slower rate of block expansion obtained when compressing with 3 seconds dwell simplifies post-compression handling and leads to better results. A practicable procedure comprises heating the material for 20 minutes on trays placed in a warm air stream (t_d, 150° F.; t_w, 93° F.; air velocity, approximately 500 feet per minute) and compressing at a pressure of 4,000 pounds per square inch with 3 seconds of dwell. When under pressure in the mold, the block attains a density of approximately 93 pounds per cubic foot.

Blocks that are ejected within 1 second after pressure is released have a density of approximately 70 pounds per cubic foot. The blocks expand rapidly and generally fall apart if they are not placed under restraint until cool. Holding presses, such as the previously described compartment type, offer a satisfactory means of restraining expansion and limiting block density to any desired value in the range of 60 to 70 pounds per cubic foot. The cooled blocks are plane-faced and satisfactorily cohesive; they do not expand when removed from the holding press.

Tight-fitting cartons do not satisfactorily prevent expansion of warm blocks. The compression faces of the block bulge the cartons both when plane-faced and when convex-faced male dies are used.

Expansion of block occurs mainly in a direction counter to the compressing motion. Linear expansion of block length and width, based on dimensions of mold and final dimensions of the cooled block, is approximately 3 percent for unrestrained blocks and 6 percent for blocks that are restrained to high densities. The difference is principally due to the fact that the holding presses apply restraint to the two compression faces of the block only. Initial rebound, or initial expansion of block thickness, is considerably greater than the expansion of block width and length. For example, when material containing 4.5 percent moisture was compressed in the Baldwin Southwark press at 4,000 pounds per square inch, the initial expansion of block thickness (based on minimum thickness of block when in the mold under high pressure and thickness immediately after ejection) ranged from approximately 25 percent for compression with 3 seconds of dwell to 37 percent for compression with zero dwell.

Data pertaining to the density and cohesiveness of unrestrained blocks are given in table 4. These

TABLE 4.—*Density and cohesive quality of unrestrained carrot blocks compressed at 4,000 pounds per square inch with 2 different periods of dwell, at various times after ejection*

3 SECONDS DWELL

Block age [1]	Block density	Cohesive quality
	Pounds per cubic foot	
5 seconds	68	Good.
10 seconds	64	Do.
15 seconds	62	Do.
30 seconds	60	Fair.
45 seconds	59	Do.
60 seconds	58	Poor.
24 hours	57	Do.

ZERO DWELL

Block age [1]	Block density	Cohesive quality
5 seconds	64	Fair to good.
10 seconds	58	Fair.
20 seconds	56	Do.
30 seconds	54	Poor.
40 seconds	53	Poor; fell apart when handled.
5 minutes	49	Do.

[1] Time after ejection.

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[4] Moisture contents determined by the 7-hour, 70° C., vacuum-oven method prescribed in Government specifications are usually about 0.6 percent lower.

results apply to diced material at the 4.5-percent moisture level, compressed in the Baldwin Southwark press at a pressure of 4,000 pounds per square inch with material heated to 150° F. It will be observed that the decrease in block density due to post-ejection expansion was considerably greater for compression with zero dwell than for compression with 3 seconds dwell. The decrease in block density was almost entirely due to expansion of block thickness. To prepare blocks with a final density of 64 pounds per cubic foot, using a compartment-type holding press to restrain expansion, the data show that it would be necessary to transfer the block to the holding press within 10 seconds after ejection in the case of blocks compressed with 3 seconds dwell, whereas a delay of only 5 seconds could be tolerated in restraining blocks compressed with zero dwell.

Tests showed that there was no significant increase in fines when compression was carried out under the various conditions described. In general the proportion of fines both in compressed blocks and in uncompressed control samples was about 1 percent.

Several hours of soaking in water at room temperature was required to effect disintegration of 1-pound blocks with densities of 72 pounds per cubic foot. Such blocks fell completely apart when soaked for about 10 minutes in water at 200° F. Dry blocks with densities of 70 pounds per cubic foot or less were also readily disintegrated by twisting the block in the hands.

Various lots of diced carrots containing approximately 5 percent moisture were compressed and subjected to organoleptic tests. In most instances these quality tests involved 1-pound blocks measuring about 3 by 5 by 1¾ inches with densities of 60 to 70 pounds per cubic foot. The blocks were prepared by heating the material to temperatures of 150° to 160° F. and compressing at pressures of 650 to 4,000 pounds per square inch with dwells ranging from 60 to 3 seconds. Results of the tests showed that compression under these various conditions has no significant effect on quality. At the same time it was demonstrated that the method employed in reconstituting the compressed product can influence product acceptability appreciably.

In evaluating organoleptic quality the compressed materials were compared with control samples that had not been compressed. The uncompressed controls were soaked for an hour in cool water and then boiled for 15 minutes. The blocks were reconstituted by various methods.

In some instances the blocks were disintegrated while dry by simply twisting them in the hands. The resulting small clusters of dice were then soaked and cooked by exactly the same method as employed for the control samples. Compressed material treated in this manner was indistinguishable from uncompressed.

Blocks disintegrated by the hot-soak procedure generally resulted in cooked material that was indistinguishable from the cooked control samples. However, in a few instances the scores indicated that quality was slightly lower for the compressed sample. This appeared to be entirely due to the use of soaking and cooking procedures that failed to rehydrate the material satisfactorily. In general it was indicated that the material should be held at the soaking temperature for 5 or 10 minutes after the block disintegrates, after which the temperature may be raised to boiling. The boiling period should be long enough to render the material tender and to effect satisfactory rehydration. The exact time is a factor which must be judged by the person preparing the food, but in general about 15 minutes is required.

Onions

Heating onion flakes containing 3 to 4 percent moisture to temperatures in the range of 120° to 140° F. was found desirable to promote satisfactory cohesion and minimize breakage.

Preliminary tests were carried out in the Carver press with the flakes heated to 140° F. The material contained 3 percent moisture. With 60 seconds dwell, a pressure of 250 pounds per square inch resulted in blocks with initial densities of about 50 pounds per cubic foot. Cooling such blocks without any form of restraint gave final densities of 46 pounds per cubic foot. A pressure of 850 pounds per square inch gave initial and final densities of 70 and 69 pounds per cubic foot, respectively. Block cohesion was good under these conditions. Wrapping blocks immediately after ejection resulted in improved cohesion and reduced expansion.

A rapid compression procedure was developed with the Baldwin Southwark press. Material containing 4 percent moisture was heated for 15 minutes in a stream of warm air (t_d, 130° F.; t_w, 79°; air velocity, 500 feet per minute). Typical results for 1-pound blocks are given in table 5.

While under pressure in the mold the blocks attained densities ranging from 75 to 87 pounds per cubic foot, depending on the pressure and dwell. The linear expansion of block length and width, based on mold dimensions and final dimensions of block, was approximately 2.7 percent. Expansion of the height dimension was considerably greater but was

Table 5.—*Results of compression of onion flakes under different conditions of pressure, dwell, and cooling procedure*

[Moisture content, 4.0 percent; temperature, 130° F.; 3- by 5-inch mold]

Pressure	Dwell	Cooling conditions	Final density	Cohesion	Remarks
Pounds per square inch	*Seconds*		*Pounds per cubic foot*		
800	0	Unrestrained	46	Fair to poor.	Slightly wedge-shaped.
800	1	...do...	50	Fair	Do.
800	15	...do...	62	Good	
1, 500	0	...do...	55	...do...	Slightly wedge-shaped.
1, 500	½	...do...	63	...do...	Do.
700	0	Holding press	50	...do...	
800	1	...do...	65	Very good.	
1, 500	0	...do...	65	...do...	
1, 500	½	...do...	69	...do...	
1, 500	1	...do...	71	...do...	

readily limited to desired values by means of holding presses. When cooled to near room temperature, the blocks no longer tend to expand. Densities of unrestrained blocks at various times after ejection are given in table 6. These values are of interest in that they indicate the lapse of time permissible between ejection and placement in holding presses which have been, set to restrict expansion when the block has attained a desired density.

Organoleptic tests involving small cylindrical blocks indicated that compression at various pressures with material at temperatures in the range of 120° to 140° F. has no significant effect on quality. The time required to effect disintegration of 1-pound, 3- by 5-inch blocks in water at 200° F. was 27 minutes for a density of 70 pounds per cubic foot and 7 minutes for a density of 50 pounds per cubic foot. Results of organoleptic tests on compressed material disintegrated by the hot-soak method and subsequently cooked indicated that there is a noticeable decrease in palatability when block density is in the neighborhood of 70 pounds per cubic foot. Compressed material with a density of 50 pounds per cubic foot compared very favorably with the uncompressed. It was noted that the compressed material develops a slightly bitter taste if the blocks are cooled very slowly.

Table 6.—*Density of unrestrained onion-flake blocks compressed at different pressures and dwells, at various times after ejection*

Age [1]	Block density in pounds per cubic foot		
	Lot A [2]	Lot B [3]	Lot C [4]
5 seconds	65	58	61
10 seconds	62	55	59
20 seconds	61	53	57
60 seconds	58	50	55
2 minutes	57	49	54
36 hours	55	46	50

[1] Time after ejection.

[2] Compressed at 1,500 pounds per square inch with zero dwell.

[3] Compressed at 800 pounds per square inch with zero dwell.

[4] Compressed at 800 pounds per square inch with 1 second dwell.

The most practicable procedure for compression of onions appears to be as follows: (1) Heat weighed portions of dehydrated onions to 130° F.; (2) charge mold and compress at 700 pounds per square inch with zero dwell; (3) cool blocks in holding presses preset to restrain expansion when block density drops to 55 or 50 pounds per cubic foot; (4) forced-convection cooling of the restrained blocks is advisable. This procedure results in plane-faced blocks that are satisfactorily cohesive and permits accurate control of final block dimensions.

POTATOES

Many complicating factors were encountered in attempting to develop a satisfactory compression procedure for dehydrated potatoes. More than any other commodity studied, the potato, by reason of its physical and physiological characteristics and the nature of its responses to environmental conditions, may almost be thought of as a group of closely related commodities rather than one commodity. Variety, stage of maturity, location where grown, with its special seasonal and soil conditions, storage conditions, and other factors all influence the responses of potatoes to dehydration and compression. Early in the work these differences became evident.

Considerable time was devoted to the study of varietal adaptability, the effects of sugar content, moisture content, and temperature of material on the compressibility of the dehydrated product, and related matters. The problems were by no means entirely solved, and considerable further work will probably be necessary to develop an entirely satisfactory process. Julienne strip and half-dice forms were used in the experiments. Compression of the extruded, or "riced," form was not attempted.

Of the eastern-grown varieties Katahdin, Chippewa, Sebago, Bliss Triumph, and Dakota Red, Bliss Triumph and Katahdin yielded products undesirably gray in color, and this grayness was accentuated on compression. Chippewa gave the most attractive product. Potatoes of the same varieties grown in Maryland gave more attractive dehydrated products and showed more cohesive quality than those grown in Maine. Differences in compressibility were not great, but the Sebago showed somewhat greater fragmentation.

The Russet Burbank variety as grown in the Pacific Northwest showed less tendency to discolor in the course of compression and subsequent rehydration than the other varieties named.

One of the outstanding characteristics of dehydrated potato strips and dice is their tendency to fracture when compressed at the moisture content of 7 percent called for by Army specifications. Their tendency to fracture under pressure and the objectionable pasty character given to the reconstituted and cooked product by the free starch present in the fines have been previously mentioned.

Several factors influence the amount of breakage. The most important which affect the cohesiveness of the block are (1) moisture content of the product, (2) percentage of natural sugars present, and (3) temperature at which compression is done.

Compression at higher moisture levels results in much less or even no fragmentation, but other practical problems arise when this method is used. Well-formed blocks may be prepared with material containing about 15 percent moisture, but either the danger of bacterial spoilage—or at least poor keeping quality—or the extra expense of post-compression drying is incurred. To insure a reasonably satisfactory storage life the moisture content must be reduced to 7 percent, or preferably even less.

Studies have shown that in raw potatoes stored at temperatures near the freezing point—a condition not uncommon in the potato-growing areas—there is an accumulation of natural sugars. It has also been shown that the presence of excessive amounts of these sugars leads to difficulties in dehydration, poor stability of the dry product in storage, and decrease in acceptability as a table product. On the other hand, the compressibility of dehydrated potatoes is improved by high sugar content. High temperatures also favor compressibility, but at the same time they hasten chemical deterioration of the product, manifested in a reddening or browning of the pieces and the development of an objectionable caramelized flavor.

An interrelationship exists between these physical and chemical factors and the table quality of the compressed product. Table quality may be effectively destroyed either by reactions that lead to scorching or by excessive fragmentation and the accompanying pastiness of the rehydrated potato. Scorching may occur during dehydration of the potatoes, precompression conditioning at elevated temperature, post-compression holding (if the rate of cooling is slow), or even during rehydration of the compressed material in hot water. The influence of high content of sugars, particularly reducing sugars, on the sensitivity of dehydrated potatoes to this type of deterioration is so marked that vigorous measures have been taken by Government procurement agencies to assure the use of low-sugar potatoes only, in plants producing for Government purchase. In spite of the advantage in compressibility noted at high sugar contents, it appears that acceptable raw material for compression must be assumed to be low in the naturally occurring reducing sugars. Keeping in view, however, the objective of "the best table product obtainable from the material available for compression," the following will indicate the best leads disclosed by the research and the methods through which they were derived.

As previously mentioned, the minimum moisture content at which blocks of satisfactory physical properties could be obtained was found to depend to a considerable extent on the total sugar content of the material. Cohesion of the compressed material was unsatisfactory with—

Total sugar content (dry basis), 2 to 3 percent.
Moisture content, less than 13 percent.
Temperature, 160° F.

Raising the moisture content to over 13 percent improved cohesion to a satisfactory degree. Other combinations of these compression conditions under which blocks of satisfactory physical properties were obtained were:

Total sugar content, 4 percent or higher.
Moisture content, 13 percent.
Temperature, 140° F.

Total sugar content, 6 percent.
Moisture content, 9 percent.
Temperature, 160° F.

Material for compression was conditioned by a number of procedures the most practical of which consisted in heating it on trays in a stream of humidified air. The degree of humidity required depended on the moisture content of the unheated material, the moisture content required for satisfactory compression, and the heating time. The heating time for material at room temperature containing 15 percent moisture and 6 percent total sugars was 5 minutes, when heating was carried out in a cross-flow air stream with wet- and dry-bulb temperatures of 124° and 145° F., respectively, and air velocity in the conditioning cabinet about 400 feet per minute. This heating procedure resulted in a gain of 0.5 percent in moisture content. With material containing 13.9 percent moisture and 3.2 percent total sugars, conditioning was satisfactorily effected, without materially altering moisture content, by heating for 20 minutes at wet- and dry-bulb temperatures of 140° and 150° F., respectively.

In order to obtain a product of acceptable organoleptic quality and to enable it to disintegrate rapidly on reconstitution, it was necessary to limit block densities to a maximum of about 50 pounds per cubic foot. High sugar contents were found to permit somewhat higher densities without as serious impairment of organoleptic quality as observed when sugar contents were low. Pressures varying from 200 to 500 pounds per square inch were required to form blocks of acceptable density with a dwell of 60 seconds. With a dwell of 3 seconds, applicable pressures ranged from 800 to 2,000 pounds per square inch. In the experimental work it was found advisable to cool the blocks in a holding press so as to retain uniform density.

The conditions under which reasonably satisfactory blocks could be made having been determined, attention was given to a study of possible methods for reducing the moisture content of the blocks to a satisfactory level. In this work several types of equipment were investigated. In view of recent developments in the field of electronics some exploratory investigations were conducted using high-frequency heating in vacuo. Under conditions employed, this was found to have little or no advantage over direct vacuum drying, particularly when the methods were compared on the basis of damage to the product (*2*). British workers have recently reported the results of similar work on drying with high-frequency heating and have pointed out a number of the practical difficulties involved (*4*).

Experiments in drying potato blocks were also carried out in a drier in which heated air was pulsated at various rates between atmospheric and superatmospheric pressures. The maximum pressure used was 35 pounds per square inch. Preliminary experiments indicated that the procedure had no practical advantage over conventional cabinet- and vacuum-drying methods.

Most of the block-drying tests were carried out in a vacuum-shelf drier or a cabinet drier. In the former, the blocks were placed flat on shelves heated in most of the tests by circulating water at 140° F. Higher temperatures caused excessive discoloration of the blocks. The cabinet drier was of the cross-flow type equipped with 24- by 42-inch metal grid trays. An air temperature of 140° F. was used in most cases. A somewhat higher drying temperature might have been used safely if the potatoes had been sulfited before dehydration. The results in brief were as follows:

Approximately 6 hours of vacuum drying with a circulating-water temperature of 140° F. (absolute pressure about 4 millimeters of mercury) was required to reduce the moisture content of 1-pound blocks having a total sugar content of 6 percent, a density of about 50 pounds per cubic foot, and measuring 6.5 by 4.1 by 1.3 inches, from 15.7 percent to the Army specification level of 7 percent. Identical blocks dried in the cross-flow cabinet (t_d, 140° F.; t_w, 84° F.; air velocity, about 400 feet per minute) reached the 7-percent moisture level in approximately 7 hours. Blocks compressed at a moisture content of about 10 percent dried in approximately two-thirds the time given in each case. The most rapid drying rates were obtained with the lowest total sugar content. For example, blocks of the same size and density containing 3.2 percent total sugars and 13 percent moisture dried in approximately 5 hours in both driers.

For obvious reasons it is very important that the moisture content of the dried blocks be reasonably uniform. This necessitates the use of material that is reasonably uniform in moisture content to begin with, careful control of the conditioning process, and uniform exposure of all blocks during drying. The results of carefully controlled experiments involving small batches of 1-pound blocks indicate that the maximum variation in block moisture content can be held at 0.6 percent. That is, in drying batches of blocks to the specification moisture level the moisture content of the individual blocks generally ranged from 6.4 to 7 percent. Moisture determinations of material cut from block centers and exteriors gave some information as to moisture gradients within the individual freshly dried blocks. The moisture level for center sections of vacuum-dried blocks was about 0.6 percent higher than for exterior sections. The corresponding difference in air-dried blocks ran as high as 1 percent. However, these gradients disappeared in 3 to 6 days when the blocks were stored in closed containers at room temperature.

Drying did not adversely affect cohesiveness of blocks or result in a noticeable change in their shape. Post-ejection expansion of block width and length coupled with contraction during drying resulted in a net linear contraction, based on mold dimensions, of approximately 1.5 percent. Block density did not change materially during the drying process, the contraction of dimensions being just about sufficient to compensate for the weight of moisture evaporated.

Rehydration of the dried blocks was effected by soaking them in water at 200° F. One-pound blocks with densities of 50 pounds per cubic foot disintegrated in 45 minutes or less when so treated. The disintegrated material generally required a cooking time of 5 to 10 minutes.

The organoleptic quality of the dried compressed material was usually acceptable if the precautions mentioned were observed. In all cases, however, the quality in at least some respects was inferior to that of the uncompressed control material that had been dried under similar conditions. The production of fines was small and of doubtful significance with respect to quality.

Most of the tests on 1-pound blocks were confined to stored material containing approximately 6 percent total sugars. This was principally due to the fact that much of the work on the drying of large blocks was carried out during the summer months when only stored raw material was available. However, a small number of tests on 1-pound units containing 3.2 percent total sugars were conducted at the close of the study, and the results supported the conclusions drawn from work on 2-ounce blocks. The tests on material of very low sugar content (2 percent total sugars) involved 2-ounce blocks only.

The bulk density of uncompressed potato strips and dice at the Army specification moisture level (7 percent) varies considerably for different conditions of dehydration but generally is about 23 pounds per cubic foot for the diced product (dice 3/16 by 3/8 by 3/8 inch) and 15 pounds per cubic foot for strips (approximate dimensions, 1/4 by 1/4 by 2 inches). Thus, since 50 pounds per cubic foot appears to be the maximum density permissible for dehydrated potato blocks, compression results in a volume reduction of approximately 54 percent for the diced product and 70 percent for the stripped product.

Owing to the extremely variable character of dehydrated products derived from the different widely grown potato varieties and the modification in these products that may readily occur under present unstandardized methods of handling raw stocks and of processing, it is emphasized that the information presented under this head should be considered merely as a summary of preliminary findings and not as a suggested procedure for immediate practical application. It is felt that much further work must be done with potatoes before it is definitely known whether an entirely satisfactory compressed product can be consistently produced.

Rutabagas

Diced and sliced rutabagas containing from 5.5 to 6.9 percent moisture (as determined by the 16-hour, 70° C., 2 millimeter-grind, vacuum-oven method) compressed satisfactorily when heated to temperatures in the range of 150° to 160° F.

In one series of experiments diced rutabagas containing 5.6 percent moisture were compressed in the Carver press with dwell held at 60 seconds and mold and material at 160° F. With compression at 450 pounds per square inch the density of the blocks immediately after ejection was 60 pounds per cubic foot. Unrestrained blocks expanded considerably while cooling to room temperature and attained a final density of approximately 51 pounds per cubic foot. Under conditions otherwise identical, a pressure of 1,350 pounds per square inch resulted in blocks with initial and final densities of 69 and 64 pounds per cubic foot, respectively. Fines produced under these condition were negligible, and the blocks were satisfactorily cohesive both before and after cooling.

In preliminary tests the dehydrated material was conditioned for compression by heating in closed containers to the desired temperature. In later work the air-stream method of conditioning was used. The material was placed on trays and exposed to a cross-flow stream of air with a velocity over the trays of approximately 500 feet per minute. The air was humidified slightly so as to prevent surface drying of the food pieces. With air wet- and dry-bulb temperatures at 95° and 150° F., respectively, the conditioning time for diced material containing 5.6 percent moisture was 20 minutes. No significant change in the moisture content of the material occurred during the conditioning process.

One-pound blocks of diced material were compressed at rapid rates in the Baldwin Southwark press. The material contained 5.6 percent moisture and was conditioned in a stream of air as described above. Compression conditions ranged from 2,000 pounds per square inch with 15 seconds of dwell to 5,500 pounds per square inch with zero dwell. The mold density, or maximum density of block during compression, ranged only from 93 to 98 pounds per cubic foot for this wide range of compression conditions. That is, mold density was fairly constant regardless of variations in pressure and dwell. The blocks tended to expand rapidly when ejected from the press, and it was necessary to employ holding presses in order to secure reasonably cohesive blocks. As was the case with beets, carrots, and various other commodities, the linear expansion of block length and width, based on mold dimensions and final block dimensions, was fairly small (about 4 percent); most of the expansion was in the thickness of the blocks. The rate of block expansion and the effect of expansion on block cohesiveness are indicated in table 7. Typical compression results when holding presses were used are given in table 8.

Any one of the sets of compression conditions listed in table 8 leads to the formation of plane-faced blocks that are acceptable from the standpoint of physical characteristics. In the case of compression at 2,000 pounds per square inch with 15 seconds of dwell, the final block density of 77 pounds per cubic foot is too high to permit rapid disintegration of the block, but a much lower final density could have been obtained simply by setting the restraining surfaces of the holding press farther apart. Of the various sets of compression conditions listed, that combining compression at 5,500 pounds per square inch with zero dwell is considered to be the most desirable because it permits completion of a compression cycle in the shortest time.

Table 7.—*Expansion of unrestrained 1-pound blocks of diced rutabagas compressed in a 3- by 5-inch mold under different conditions of pressure and dwell*

Age [1]	Block thickness [2]	Block density	Cohesive quality
5,500 Pounds per Square Inch Pressure, Zero Dwell			
	Centimeters	*Pounds per cubic foot*	
6 seconds	4.87	59	Fair.
15 seconds	5.47	53	Do.
60 seconds	5.98	48	Poor.
2 minutes	6.16	47	Very poor.
3 minutes	6.26	46	Could not be handled.
2,500 Pounds per Square Inch Pressure, 3 Seconds Dwell			
5 seconds	4.47	65	Good.
15 seconds	4.97	58	Fair.
60 seconds	5.45	53	Poor.
2 minutes	5.68	51	Do.
4 minutes	5.87	49	Very poor.
2,000 Pounds per Square Inch Pressure, 15 Seconds Dwell			
10 seconds	4.12	70	Good.
15 seconds	4.27	68	Do.
60 seconds	4.74	61	Fair.
2 minutes	4.95	59	Do.
18 minutes	5.42	53	Fair to poor.

[1] Time after ejection from press.

[2] Expansion of block length and width after ejection was negligible.

Table 8.—*Block density and cohesive quality of dehydrated rutabagas compressed under different conditions of pressure and dwell*

[Moisture content, 5.6 percent; temperature, 150° F.; Baldwin Southwark press; 3- by 5-inch mold; 1-pound blocks; all blocks cooled in wooden holding press]

Pressure	Dwell	Final block density [1]	Cohesive quality
Pounds per square inch	*Seconds*	*Pounds per cubic foot*	
4,000	1	65	Good.
2,500	3	71	Do.
5,500	1	67	Do.
5,500	0	66	Do.
2,000	15	77	Very good.

[1] Determined immediately after removing blocks from holding press—no significant change 24 hours later. Expansion of each block was restrained within 3 seconds after ejection; the tabulated densities are, therefore, practically the same as the block densities immediately after ejection.

Visual examination of the compressed blocks indicated that compression under the conditions described does not result in physical damage to the dehydrated material. Analyses for fines showed that practically no pulverization occurs, the fines present in the compressed and uncompressed samples being practically identical. Fines were determined by rehydrating the materials overnight and then making the separation by means of sieves, as previously described. In general, the fines contained in both the compressed and uncompressed products amounted to slightly less than 1 percent.

One-pound blocks of dice, approximately 1.8 by 3 by 5 inches, with density at 63 pounds per cubic foot, required about 3 hours to disintegrate when immersed in water at room temperature. Since this was considered excessively long, tests were made with water heated to 200° F. The periods required for disintegration of 1-pound blocks of different density in water at 200° F. were as follows:

Block density (pounds per cubic foot):	*Disintegration time* (*Minutes*)
65.3	6
66.1	8
70.8	15

It was also found possible to disintegrate the dry blocks of dice rapidly by simple hand methods without damaging the material appreciably.

In the organoleptic tests the uncompressed controls were soaked in cool water for 1 hour and then boiled for 15 minutes. Blocks disintegrated by hand were reconstituted in the same way, and the resulting material was found to be indistinguishable from the cooked control samples. However, when the compressed blocks were disintegrated by the hot-soak procedure the compressed material generally received lower scores for texture and flavor than did the controls. Possibly the lowering of quality was due to the fact that the temperature was raised to boiling as soon as the block disintegrated. It may be that using a lower soaking temperature or soaking the disintegrated material for a short time before heating to the boiling point would maintain quality. It would appear desirable to determine these points by further experiments.

SWEETPOTATOES

Because the sweetpotato is relatively high in sugar content and rather stable as a dehydrated product, it can be made into compressed blocks with much less difficulty than the white or Irish potato. There are two main types of sweetpotatoes, the southern or moist type, well represented by the Porto Rico variety, and the Jersey or dry type, of which the Maryland Golden and Big Stem Jersey are well-known representatives. In order to have a clear understanding of what to expect from this commodity, another fact needs to be borne in mind: the character of the dehydrated product from freshly dug sweetpotatoes differs considerably from that of the product from potatoes cured and stored in the usual way. This difference is manifested in a higher total polysaccharide content, calculated as starch, in the freshly dug potatoes, and a higher total sugar content in the cured sweetpotatoes.

These differences are not so marked in the dry or Jersey type as in the moist southern types. The practical significance of this is that both the dry and the freshly dug moist types are less readily compressed into cohesive blocks. In spite of these differences, however, both types, at all market and manufacturing stages, have relatively high sugar contents, and it would appear that with suitable compression conditions they should yield satisfactory blocks. Further research, however, is necessary to determine for all varieties just what those conditions may be. The experiments reported here were performed on commercial dehydrated products.

Experiments with material of the Porto Rico variety, of different moisture contents and heated to various temperatures, showed that acceptable blocks can be made under a considerable range of compression conditions. There were, however, marked differences in the compression results obtained with batches of material secured from commercial dehydrators located in different growing areas.

One batch of diced material containing 4 percent moisture made good blocks when heated to 158° F. and pressed at 2,800 to 3,800 pounds per square inch with 15 seconds of dwell. Immediately after ejection from the press these blocks had densities of 75 to 77 pounds per cubic foot. Heating to a temperature of 140° F. gave good blocks of slightly lower density. Results obtained with two other lots of diced material under a considerable range of compression conditions are given in table 9. The warm blocks tended to expand rapidly when ejected from the press and it was found necessary to cool them under restraint. The blocks were removed from the holding press when cooled and were then found to have no significant tendency to expand or to lose cohesiveness on standing.

The most practical procedure developed in the course of the work was to heat the material on wire-mesh trays in a slightly humidified air stream (t_d, 150° F.; t_w, 105° F.; air velocity, 500 feet per minute) for 20 minutes, which caused no appreciable change in moisture content, and then to compress at pressures ranging from 3,000 to 4,000 pounds per square inch. The dwell required for the formation of satisfactory blocks ranged from 3 to 15 seconds for two different lots of material, as shown in table 9. When provision was made for rapid ejection after compression, the final block density after cooling in a holding press was approximately 65 pounds per cubic foot. When considerable time was required to eject the block from the mold, as in compression with the Elmes press, the final density was about 60 pounds per cubic foot. The total linear expansion of block length and width, based on dimensions of the cooled block and of the mold cavity, ranged from 2 to 5 percent; the actual values obtained under a given set of conditions differed considerably for lots of different origin.

Compression under the conditions indicated in table 9 of materials at 150° to 160° F. produced only a small amount of fines. For example, in material containing approximately 6 percent moisture, fines before compression ranged from 1.4 to 1.7 percent; the blocks, when compressed slowly or rapidly at low or at high pressures, contained not more than 3 percent of fines. One-pound blocks, measuring approximately 1.7 by 3 by 5 inches and with densities of about 69 pounds per cubic foot, disintegrated in 10 minutes or slightly less when immersed in water at 200° F.

Cooking time required for the disintegrated material was approximately 10 minutes at 212° F. Uncompressed controls employed in the organoleptic tests were soaked in cool water for 1 hour and then boiled for 10 minutes. With these reconstitution methods

Table 9.—*Block density and cohesive quality of dehydrated sweetpotatoes, Porto Rico variety, compressed under different conditions of temperature, pressure, and dwell*

Lot No.[1]	Press	Temperature of press and material	Pressure	Dwell	Block density		Cohesive quality of cooled block [3]
					Initial	Final [2]	
		°F.	*Pounds per square inch*	*Seconds*	*Pounds per cubic foot*	*Pounds per cubic foot*	
C105R	Baldwin Southwark	160	4, 000	7	[4] 96	....	Poor.
Do	do	160	4, 000	15	[4] 96	66	Fair.
Do	do	160	4, 000	30	[4] 96	69	Fair to good.
Do	do	150	4, 000	15	[4] 96	63	Fair.
Do	do	150	5, 500	10	[4] 97	60	Do.
C70R	do	150	4, 000	3	[4] 96	67	Good.
Do	do	150	3, 000	3	[4] 94	67	Do.
Do	Elmes	160	3, 000	3	....	65	Do.
Do	do	150	3, 000	3	[5] 66. 5	59	Fair.
Do	do	150	4, 000	3	[5] 68	59	Good.
Do	Carver	150	600	30	[5] 68	....	Poor.
Do	do	150	800	30	[5] 71	63	Fair.
Do	do	150	1, 000	30	[5] 75	67	Good.
Do	do	140	1, 000	30	[5] 72	64	Fair.
Do	do	160	400	30	[5] 65	60	Do.
Do	do	160	600	30	[5] 70	62	Good.
Do	do	160	800	30	[5] 76	68	Do.
Do	do	160	1, 000	30	[5] 78	69	Very good.

[1] Lot C105R: Total sugar content, dry basis, 37 percent; moisture content, 6.1 percent. Lot C70R: Total sugar content, 35 percent; moisture content, 6.6 percent. The lots were obtained from two different commercial dehydrators.

[2] All blocks restrained in holding presses until cool.

[3] Material rated "fair" was considered acceptable.

[4] The mold density of the block; i. e., block density immediately prior to release of high pressure.

[5] Value determined immediately after ejection of the block from the mold.

the rehydration ratio was slightly higher for the compressed samples than for the controls. Also, organoleptic quality was little affected, and in most cases no difference between compressed material and controls could be detected. The combination of a high conditioning temperature (176° F.), a press temperature of 140° F., and a pressure of 3,800 pounds per square inch, however, resulted in injury to both flavor and texture.

Experiments with diced sweetpotatoes of the Maryland Golden variety (a dry type) at different moisture levels and with different conditioning temperatures gave disappointing results. Material having 5 percent moisture failed to give satisfactory blocks when heated to 158° F. and compressed at pressures ranging from 2,800 to 5,200 pounds per square inch with 15 seconds of dwell. There were also excessive breakage and crushing. Under the same range of conditions, fair blocks, as they came from the press, were obtained from material containing 7.5 percent moisture. These had a density of 63 to 67 pounds per cubic foot, but after cooling the coherence was poor and fragmentation and crushing were found to be rather high.

Diced dehydrated sweetpotatoes prepared commercially from an unnamed white-skinned, light-fleshed variety of the dry type also compressed less satisfactorily than the Porto Rico. This material, containing 7.1 percent moisture, was heated to 160° F. in closed containers to avoid any possibility of surface drying. Pressures in the range of 1,000 to 1,500 pounds per square inch at 30 seconds of dwell resulted in fairly satisfactory blocks with initial densities of 66 to 71 pounds per cubic foot. The blocks were restrained in a holding press until cool and had final densities ranging from 64 to 70 pounds per cubic foot. There was no noticeable effect of the treatment on organoleptic quality. The uncompressed material contained 1.8 percent fines, whereas the fines contained in the compressed product amounted to approximately 5 percent.

The coherence of the cooled blocks of this light-fleshed variety was only fair; pieces tended to chip off the edges unless they were very carefully handled. Pressures lower than 1,000 pounds per square inch resulted in inferior blocks. Tight paper wrappers proved to be unsatisfactory as a substitute for holding presses in restraining the blocks during cooling; the compression faces of the wrapped blocks bulged objectionably. Tests at rapid compression rates were not conducted with this variety, but results with 30 seconds of dwell indicated that very high pressures would be required to give satisfactory results.

Termination of the project while this work was in progress prevented determination of the conditions best adapted to the making of satisfactory blocks from sweetpotatoes of the dry type.

COMPRESSION OF SPECIFIC DEHYDRATED FRUITS [5]

Apple Nuggets

Dehydrated apple nuggets [6] at moisture levels ranging from 1.3 to 2.1 percent compressed satisfactorily when heated to 120° or 130° F. One-pound blocks were compressed at 120° F. in the Elmes press at pressures of 100 to 1,000 pounds per square inch. The press was fitted with a mold having a 6⅝- by 2¼-inch cavity. The mold was maintained at a temperature of 120° F. Blocks compressed at pressures ranging from 200 to 1,000 pounds per square inch with dwells of ½ to 30 seconds were of good cohesive quality and of desirably high density. Compression at 100 pounds per square inch resulted in blocks that were satisfactorily cohesive, but block density was unsatisfactorily low. The warm blocks tended to expand rapidly, and in order to prevent excessive expansion it was found desirable either to wrap the blocks or to place them in a holding press until cool. Densities attained with compression at minimum and maximum pressures and dwells are given in table 10.

Table 10.—*Densities of apple nuggets under various conditions of compression in the Elmes press and paper-wrapped for cooling*

[Temperature, 120° F.; moisture content, 1.3 to 2.1 percent]

Pressure	Dwell	Density as ejected	Density after cooling
Pounds per square inch	*Seconds*	*Pounds per cubic foot*	*Pounds per cubic foot*
100	½	29. 3	28. 7
100	30	35. 6	34. 9
1,000	½	67	61
1,000	30	76	73

Within the range of 1.3 to 2.1 percent moisture no relationship was found between moisture content and block density. At any compression pressure the density of the ejected blocks increased with the time of dwell. The wrapped blocks swelled slightly while cooling, and as a result the compression faces of the blocks became somewhat convex. Bulging was greater after the shorter dwells. It was difficult to secure a uniformly tight wrap, and for that reason final block densities varied considerably. However, when blocks were cooled in holding presses, density of block was readily held constant for a given set of compression conditions, and block faces did not bulge. It would therefore appear that the use of holding presses is essential where uniformity of density and good appearance are important considerations.

Tests involving rapid compression were also conducted with the Baldwin Southwark food press. As compared with the Elmes press, the Baldwin Southwark press provides for much faster ejection of blocks and greater ram speeds. For these reasons alone the results obtained with these two presses could be expected to differ considerably.

The material for the tests was weighed into small wire-mesh baskets and conditioned by heating for 20 minutes in an air stream with dry-bulb temperature 130° F., wet-bulb temperature 73° F., and air velocity 500 feet per minute. The material initially contained 1.8 percent moisture, and results of analyses on compressed blocks showed no significant change in moisture content in the over-all compression process. The mold was maintained at 130° F. and measured approximately 3 by 5 inches. Summarized results for various compression conditions are given in table 11.

It will be observed in table 11 that the density of the block while under pressure in the mold was practically constant regardless of the pressure applied. However, as will be seen in table 12, it was found that compression conditions have a material effect on the rate and degree of expansion after the block is ejected.

Table 11.—*Densities of apple nuggets under various conditions of compression in the Baldwin Southwark press*

[Temperature, 130° F.; moisture content, 1.8 percent]

Pressure	Dwell	Mold density [1]	Cooling conditions	Final block density	Block cohesiveness
Pounds per square inch	*Seconds*	*Pounds per cubic foot*		*Pounds per cubic foot*	
4, 000	0	100	Not restrained. . .	55	Good.
4, 000	0	100	Holding press. . . .	[2] 68	Very good.
2, 000	3	101	Not restrained. . .	61	Good.
1, 200	0	99	Holding press. . . .	[2] 68	Very good.
1, 200	0	100	Not restrained. . .	53	Good.
1, 200	3	100	Holding press. . . .	[2] 69	Very good.
800	0	99	Not restrained. . .	52	Fair.
800	0	100	Holding press. . . .	[2] 67	Good.

[1] Density of block while in mold under high pressure.

[2] Block expansion was restrained within 20 seconds after ejection.

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[5] Data on the reduction in volume brought about by compression are given in table 18, p. 44.

[6] [U. S.] Army Quartermaster Corps. tentative specification, apple nuggets; dehydrated. CQD No. 78B, 7 pp. 1944. [Processed.]

TABLE 12.—*Expansion during cooling of unrestrained apple-nugget blocks compressed under different conditions*

[Material compressed at 130° F. in Baldwin Southwark press; 1⅓-pound blocks, 3- by 5-inch mold; blocks cooled in still air at room temperature]

800 POUNDS PER SQUARE INCH PRESSURE, ZERO DWELL

Block age [1]	Block height [2]	Block density	Cohesive quality
	Centimeters	*Pounds per cubic foot*	
10 seconds	5. 67	69. 8	Good.
1 minute	6. 83	58. 0	Do.
3 minutes	7. 23	54. 8	Do.
6 minutes	7. 37	53. 8	Fair.
9 minutes	7. 44	53. 3	Do.
24 hours	7. 60	52. 1	Do.

4,000 POUNDS PER SQUARE INCH PRESSURE, ZERO DWELL

Block age [1]	Block height [2]	Block density	Cohesive quality
10 seconds	5. 48	72. 8	Very good.
1 minute	6. 48	61. 5	Good.
3 minutes	6. 60	60. 4	Do.
6 minutes	6. 76	59. 0	Do.
9 minutes	6. 82	58. 5	Do.
24 hours	7. 19	55. 5	Do.

2,000 POUNDS PER SQUARE INCH PRESSURE, 3 SECONDS DWELL

Block age [1]	Block height [2]	Block density	Cohesive quality
10 seconds	5. 34	74. 9	Very good.
1 minute	6. 07	65. 9	Do.
3 minutes	6. 28	63. 7	Good.
6 minutes	6. 40	62. 6	Do.
9 minutes	6. 43	62. 2	Do.
24 hours	6. 58	60. 7	Do.

[1] Time after ejection from mold.

[2] Practically no expansion of block length or width occurred after ejection.

Measurement of mold dimensions and of the cooled blocks showed that the expansion of block length and width is such that the dimensions of the mold cavity should be about 6 percent smaller than the dimensions of the desired block. Expansion after ejection was almost entirely confined to the height dimension of the block. Blocks compressed under identical conditions did not always attain the same height when allowed to expand, and this led to considerable variation of block density. For example, final densities for expanded blocks that had been compressed at 4,000 pounds per square inch with zero dwell ranged from 53.7 to 57.7 pounds per cubic foot. However, the use of holding presses made it possible to avoid this kind of variation and at the same time made feasible the attainment of higher final densities.

The blocks had no significant tendency to expand when cooled to room temperature and retained their cohesiveness on standing. Because of the hygroscopic nature of this commodity, long exposure to normal atmosphere was carefully avoided and cooling conditions were selected to avoid significant absorption of moisture.

It will be observed from the data in table 12 that higher block densities cannot be secured if there is considerable delay in restraining expansion. Obviously, a holding press with properly spaced platens would enable the operator to restrict block density to any desired value by restraining at the proper time after ejection.

Disintegration of blocks was best effected through immersion in heated water. The time required was found to be excessive when the blocks were soaked in water at room temperature. For example, 1-pound blocks (density 54 pounds per cubic foot, dimensions approximately 3 by 5 by 2.1 inches) did not break up completely when soaked in water at 70° F. for 24 hours. Complete disintegration was obtained in a practical length of time with water at 200° F. Results for typical blocks from a 3- by 5-inch mold were as follows:

	Disintegration time
1-pound blocks:	*(Minutes)*
Block density 68 pounds per cubic foot	26
Block density 62 pounds per cubic foot	25
1⅓-pound blocks: Block density 66 pounds per cubic foot	25

Blocks with densities ranging from 53 to 67 pounds per cubic foot were disintegrated by this hot-soak procedure and then cooked for the organoleptic tests. Comparison of the resulting sauce with that prepared from the uncompressed nuggets proved that compression has no significant effect on flavor, color, taste, texture, or appearance. Each of these characteristics was rated as "very good" or "good." The control samples were rehydrated by simmering at 212° F. for 30 minutes. There was no significant difference in the rehydration ratios for the compressed and uncompressed samples.

APRICOTS

The work on apricots was restricted to dehydrated halves at moisture levels of 18.7 and 13.2 percent. Most of the compressions were conducted with the Carver press and involved formation of 4-ounce blocks. A few blocks weighing 16 pounds were formed in a 10- by 10-inch mold in the Elmes press. The Baldwin Southwark press was not available for work on this commodity. Compression was carried out at two temperature levels, 77° and 120° F. The relations of block density to various compression conditions are given in table 13.

Table 13.—*Densities of blocks of apricot halves under various compression conditions*

Temperature of material (°F.)	Moisture content	Pressure	Dwell	Block density	
				Initial [1]	1 day later [2]
	Percent	*Pounds per square inch*	*Seconds*	*Pounds per cubic foot*	*Pounds per cubic foot*
77	13. 2	50	60	69	47
77	13. 2	100	60	80	55
77	13. 2	300	60	81	64
77	13. 2	600	60	82	69
77	13. 2	900	60	84	67
77	13. 2	1, 500	60	84	64
77	13. 2	3, 000	60	84	66
77	13. 2	5, 000	60	84	64
77	13. 2	300	0	74	59
77	13. 2	1, 500	0	81	62
77	13. 2	300	15	80	62
77	13. 2	1, 500	15	81	61
120	13. 2	50	60	80	59
120	13. 2	100	60	83	66
120	13. 2	300	60	86	73
120	13. 2	600	60	86	73
120	13. 2	900	60	86	73
120	13. 2	1, 500	60	86	73
120	13. 2	3, 000	60	86	75
77	18. 7	100	60	79	59
77	18. 7	300	60	78	55
77	18. 7	900	60	80	56

[1] Determined immediately after ejection of the block.

[2] Blocks continued to expand upon further standing.

Injury to skins was first noted at 1,500 pounds per square inch with compression at room temperature, and at 900 pounds per square inch with compression at 120° F. Good initial cohesion was not produced at pressures under 100 pounds per square inch. Pressures higher than 300 pounds per square inch with dwells of 15 and 60 seconds had very little effect on the density of the ejected blocks.

As indicated in table 13, there is a marked decrease in block density when the blocks are left unrestrained for 24 hours. This decrease in density is due almost entirely to expansion counter to the direction of compression; that is, expansion results in an increase of block height, but length and width dimensions remain practically constant. Compression at a higher temperature lessens the tendency to expand. Restraint in holding presses for 24 hours after ejection to fix block shape and dimensions was not successful, as the results were not permanent. Wrapping blocks was likewise unsatisfactory as a restraining method; the block faces bulged excessively. Immediate boxing of the blocks was found to be essential to maintenance of high block density.

Rehydration tests were conducted with blocks weighing 4 ounces. The blocks, and also samples of the uncompressed material, were soaked in cool water for 17½ hours and rehydration ratios were then determined. Regardless of the pressure and temperature employed in compression, there were no significant differences between the rehydration ratios for the blocks and the uncompressed controls.

As previously mentioned, a few 16-pound blocks were formed in a 10- by 10-inch mold. In forming these blocks it was necessary to compress with a dwell of 15 seconds or longer. Results indicated that dwells considerably shorter than 15 seconds can be used with 4-ounce blocks, but limitations of the equipment available for compression in large molds made it impossible to show whether this holds for large blocks. Immediately after compression the 16-pound blocks were placed in wooden boxes made from ¼-inch shook, and the boxes were then nailed and strapped.

The bulk density of the uncompressed apricots that contained 13.2 percent moisture was 35 pounds per cubic foot. Compression at 300 pounds per square inch, at room temperature, with a dwell of 15 seconds results in blocks with initial densities of approximately 80 pounds per cubic foot. Allowing for about 5 percent expansion during the packing operation, the final density of the boxed block is 75 pounds per cubic foot. Thus the volume reduction, based on initial and final densities of the dried fruit, is approximately 53 percent.

CRANBERRIES

Compression tests on cranberries involved whole fruit dehydrated to a moisture content of 5.5 percent. Compression was carried out with pressures ranging from 400 to 4,000 pounds per square inch with the material at room temperature (70° F.), 110°, 150°, 160°, and 180° F.

Compression at room temperature resulted in blocks of poor cohesive quality; at higher temperatures cohesiveness was considerably improved. Optimum cohesive quality was obtained when compression was applied to material at 150° F., with the mold at room temperature. With the mold heated to 150° F., the compressed material tended to stick to the metal dies, and surface material tended to curl and flake off the blocks when they were ejected from the press. The use of cool molds keeps the material from sticking to metal surfaces and, where compression involves several seconds of dwell, a beneficial effect is obtained through cooling of the block surface. This cooling reduces the plasticity of the compressed material and tends to set the surfaces of the block and to reduce post-ejection expansion. Naturally this effect is more pronounced the thinner the block and the longer the dwell.

In compressing thick blocks of cranberries with dwells as long as 30 seconds the cooling effected by the mold was not sufficient to retard block expansion materially. As a result the block density immediately after ejection was considerably lower for thick blocks than for thin ones. In fact, for 1-pound blocks measuring approximately 3 by 5 by 2 inches the expansion during ejection was so great as to produce blocks of objectionably low density. However, it was found possible to increase block density by applying a slight force by hand to the compression faces of the block immediately after ejection. The block can then be restrained and cooled at the higher density.

As an example, a test is cited in which a 1-pound block was compressed in a 3- by 5-inch mold at 2,000 pounds per square inch with 5 seconds of dwell, material at 150° F., and the mold at a temperature of 70° F. The blocks attained a density of about 90 pounds per cubic foot while under maximum pressure in the press, and the block density immediately after ejection (about 1 second after release of maximum pressure) was approximately 37 pounds per cubic foot. The density of the block was readily increased to 52 pounds per cubic foot by pressing the two compression faces of the block between the hands, and it was then possible to cool the block at this higher density. It would appear to be a very simple matter to construct a holding press that would be capable of accomplishing this slight recompression mechanically. For example, a holding press of the type shown in figure 12 could be constructed with diminishing clearance between restraining surfaces at the charging end so as to increase block density to the desired value. The pressure required for recompression to a density of 52 pounds per cubic foot is about 4 pounds per square inch.

Results obtained in typical tests with 2-ounce and 16-ounce blocks are summarized in table 14. In these tests the material was heated at 150° F. and the molds maintained at 70° F. The mold used with the Carver press in forming 2-ounce blocks was of the 2- by 3-inch size. The 16-ounce blocks were formed in a 3- by 5-inch mold. Thus, while under pressure in the mold the 16-ounce blocks were approximately 3 times as thick as the 2-ounce blocks. Since this led to a considerable difference in the degree of cooling effected during compression, the densities of the ejected blocks differed considerably in the two cases. The values given in the table under "Initial block density" were determined immediately after ejecting the block from the press.

Under the compression conditions described in table 14 the blocks attained densities ranging from 89 to 94 pounds per cubic foot while under pressure in the press. Regardless of the compression conditions it was necessary to restrain expansion of block thickness as soon as the block was ejected. The expansion of the block in a direction perpendicular to the axis of compression was only about 4 percent.

The cooled blocks were desirably cohesive, but they expanded perceptibly in several hours if not restrained in some manner. In practice, they should be tightly wrapped or packed in wooden boxes. Blocks that were tightly wrapped in cellophane immediately after cooling in a holding press decreased in density from an initial value of 52 pounds per cubic foot to a final stable value of 45 pounds. At the lower density the wrapper fitted the blocks very tightly and prevented further expansion. The decrease in density was almost entirely due to expansion of block thickness. Bulging of the compression faces of the wrapped expanded blocks was barely apparent. Close-fitting

TABLE 14.—*Effects of various compression conditions on block density and cohesive quality of dehydrated whole cranberries*

[Material at 150° F.; molds at 70° F.; bulk density of uncompressed material, 12.7 pounds per cubic foot]

Press	Approximate block weight	Pressure	Dwell	Initial block density	Initial cohesion	Block density after cooling	Cohesion after cooling
	Ounces	*Pounds per square inch*	*Seconds*	*Pounds per cubic foot*		*Pounds per cubic foot*	
Carver	2	400	30	44	Fair	[1] 43	Good.
	2	800	30	56	Good	[1] 55	Do.
	2	1,200	30	60	do	[1] 59	Do.
Elmes	16	800	30	42	Fair	[2] 52	Do.
	16	2,000	5	37	do	[2] 52	Do.
Baldwin Southwark	16	500	30	42	do	[1] 52	Do.
	16	2,000	5	41	do	[2] 52	Do.
	16	2,000	30	54	do	[1] 50	Do
	16	4,000	5		do	[2] 52	Do

[1] Block was cooled in a holding press of the compartment type, such as shown in figure 11.

[2] The ejected block was subjected to a slight compressive force to increase block density and then restrained in a holding press at this higher density until cool.

cartons gave approximately the same result as the cellophane wrappers.

Because of the nature of cranberries and the form in which they are generally presented as food, it was considered unnecessary to determine the percentage of fines produced as a result of compression. It may be mentioned, however, that there was no visual evidence of crushing or breakage when the berries were compressed after being heated to temperatures of 110° F. or higher. A very small amount of fines was formed when the berries were compressed at room temperature.

Samples of compressed and of uncompressed material were compared as to organoleptic quality and ease of rehydration. The samples employed in the organoleptic tests were rehydrated and cooked by the conventional procedure (*7*). In determining rehydration ratios the uncompressed and compressed samples were boiled in water for 14 minutes without prior soaking, and drained weights were obtained by filtering the reconstituted materials.

Blocks compressed according to procedures outlined in table 14, with densities of 50 to 55 pounds per cubic foot, were easily broken apart by hand. Two-ounce blocks and pieces of similar weight broken from pound blocks fell apart in approximately 3 minutes when immersed in water at 200° F. Organoleptic tests showed that the resulting material formed a cooked product that was indistinguishable from that prepared from the uncompressed material. There were no significant differences between rehydration ratios for uncompressed and compressed samples.

As indicated, compression at longer dwells results in less expansion during ejection and in slower expansion immediately after ejection. In spite of these advantages, compression with dwells of 30 seconds would not be practical with a single-block press, since it would lead to low productive capacity. The most practicable procedure for preparing blocks weighing 1 pound or less would appear to consist in pressing the cranberries at 150° F. in a cool mold at a pressure of 2,000 pounds per square inch with 5 seconds of dwell. The ejected blocks should be restrained in a holding press at a density of about 55 pounds per cubic foot and subsequently wrapped and packed in containers capable of restraining expansion. Block densities obtained with this procedure will range from about 45 to 55 pounds per cubic foot, depending on the type of container, and the volume reduction will range from 72 to 77 percent.

The compression characteristics of cranberries indicate that it may be advantageous to compress the material directly in cans or other containers instead of employing procedures that result in the formation of cohesive blocks. Cohesion of the compressed mass within the container would not be important, so that it would probably not be necessary to heat the material before compression.

PEACHES

Dehydrated peach halves were found to respond to compression in much the same way as dehydrated apricot halves of similar moisture content. The peach halves used in the tests contained 10.7 percent moisture. Compressions were carried out in the Carver laboratory press and in the Elmes press. Blocks formed in the Carver press weighed 4 ounces, whereas those formed in the Elmes press weighed 14 pounds. Tests were made with material heated to 120° F. and at room temperature. Molds were maintained at the same temperature as the material. Dwells of 30 seconds and 60 seconds were used, but it is possible that acceptable results can be secured with shorter dwells. The Baldwin Southwark press, which would have permitted experimentation with shorter dwells, was not available for work on this commodity.

Compression results obtained with the Carver press are summarized in table 15. It should be particularly noted that a dwell of 60 seconds was used in the tests with this press.

TABLE 15.—*Density, degree of skin injury, and cohesive quality of dehydrated peach halves under various compression conditions*

[Moisture content, 10.7 percent; Carver press; dwell, 60 seconds; 4-ounce blocks; expansion not restrained]

Pressure	Temperature	Block density		Skin injury	Initial cohesive quality
		Initial [1]	1 day later [2]		
Pounds per square inch	*°F.*	*Pounds per cubic foot*	*Pounds per cubic foot*		
50	79	59	......	Negligible	Fell apart.
100	79	69	58	do	Poor.
300	79	81	58	do	Good.
600	79	81	63	Slight	Do.
900	79	81	63	do	Do.
1, 500	79	81	64	Appreciable	Do.
2, 500	79	82	64	Serious	Do.
50	120	65	......	Negligible	Very poor.
100	120	74	59	Slight	Poor.
300	120	78	68	do	Fair.
600	120	78	69	Appreciable	Good.
900	120	79	69	Serious	Do.
1, 200	120	77	70	do	Do.

[1] Determined immediately after ejection of the block.

[2] Blocks continued to expand upon further standing.

From table 15 it will be seen that initial block density reached a maximum at a pressure of about 300 pounds per square inch and that higher pressures were objectionable because they resulted in breakage of skins. Damage to skins was negligible when material at room temperature was compressed at 300 pounds per square inch, but with material at 120° F. damage occurred at a pressure of 100 pounds per square inch. Pulp was extruded from the mold at relatively high pressures. Extrusion was first observed at a pressure of 2,500 pounds per square inch when the material was compressed at room temperature and at 600 pounds per square inch when the material was at 120° F. The results show definitely that dehydrated peach halves at the 11-percent moisture level should be compressed at room temperature and at a pressure of 300 pounds per square inch when the process involves a dwell of 60 seconds.

Under all compression conditions imposed, the blocks had a pronounced tendency to expand after ejection. In consequence, immediate packaging in rigid containers was found to be essential to maintenance of initial block density. Post-ejection expansion was almost entirely confined to the thickness dimension; expansion perpendicular to the axis of compression was negligible. The restraint offered by tight paper wraps was not sufficient to prevent objectionable bulging of the compression faces of the blocks.

Blocks formed at room temperature and 120° F. through application of pressures up to 900 pounds per square inch with 60 seconds dwell rehydrated as readily as did the uncompressed dried fruit when soaked in water for 17½ hours.

Blocks weighing 16 pounds were formed in a 10- by 10-inch mold with the Elmes press. The material was compressed at room temperature with 30 seconds dwell at a pressure of 300 pounds per square inch. Immediately after ejection the blocks were placed in boxes made from ¼-inch shook, and the boxes were then nailed and strapped. This method of packing restrained block expansion and resulted in a final block density of 73 pounds per cubic foot. Since the uncompressed peaches had a density of 36 pounds per cubic foot, the procedure resulted in a volume reduction of approximately 47 percent.

PRUNES

Whole prunes that had been dried to a moisture content of 12.4 percent were used in compression experiments. The count was approximately 55 prunes per pound, and the weight ratio of pulp to pits was approximately 5.6 to 1.

The material was compressed in the Carver laboratory press and in the Elmes press. Tests with the Carver press consisted in pressing 5-ounce blocks at various pressures with 60 seconds dwell and with the material either at room temperature or at 120° F. The Elmes press was used in pressing 16-pound blocks with 30 seconds dwell.

Results obtained with the Carver press, which are briefly summarized in table 16, showed that compression of the material at 120° F. has no advantage over compression at room temperature. Also, it was indicated that compression at 60 seconds dwell should be carried out at a pressure of about 300 pounds per square inch. A pressure of 600 pounds per square inch resulted in some damage to pits, while at 300 pounds such damage was negligible. Damage to skins occurred at 100 pounds per square inch when the material was at 120° F. and at 600 pounds per square inch when compression was conducted at room temperature. At room temperature and at a pressure of 600 pounds per square inch, damage to skins was slight. Blocks compressed at pressures up to 900 pounds per square inch, at room temperature or 120° F., rehydrated quite as readily as did the un-

TABLE 16.—*Compression characteristics of dehydrated whole prunes*

[Moisture content, 12.4 percent; compression at 60 seconds dwell, in the Carver press; blocks not restrained after ejection]

Pressure	Temperature	Initial density [1]	Initial cohesion	Cohesion after standing	Pit damage
Pounds per square inch	*° F.*	*Pounds per cubic foot*			
100	76	79	Poor...	Fell apart after 5 minutes.	Negligible.
300	76	80	Fair .	Very poor after 30 minutes.	Do.
600	76	80	do ..	.... do ...	Slight.
900	76	81	. do...	Poor after 30 minutes.	30 percent broken.
1, 200	76	83	Good .	do .	75 percent broken.
100	120	78	Poor. .	Fell apart after 5 minutes	Negligible
300	120	79	... do...	Fell apart after 10 minutes.	Do.
600	120	79	do...	Fell apart after 20 minutes	Slight, 6 percent broken.
900	120	80	Fair	do	45 percent broken

[1] Determined immediately after block was ejected from mold.

compressed prunes when soaked for 17½ hours in water at room temperature.

Blocks compressed at room temperature or at 120° F. had a serious tendency to fall apart shortly after compression. A tight cellophane wrap was tried as a means of holding the block together and preventing an excessive decrease of density, but the wrapper did not prevent objectionable bulging of the compression faces of the block. Packing the blocks in rigid containers, however, overcame this difficulty. For example, in tests with the Elmes press the material was compressed in a 10- by 10-inch mold at a pressure of 300 pounds per square inch with 30 seconds of dwell, and immediately after ejection the blocks, weighing 16 pounds each, were placed in wooden boxes. The boxes were made of ¼-inch shook and were nailed and strapped immediately after being filled. This procedure prevented bulging and maintained block density at 73 pounds per cubic foot, but extreme care is required in handling the blocks and a moderate delay in packing results in the falling apart of the block.

All things considered, it appears that dehydrated prunes should be compressed directly in containers with a sleeve insert as protection for the container walls. This sleeve could be backed up by a mold outside the container. Compression at room temperature with a 1-minute dwell at 100 pounds per square inch would raise the density of prunes at the 12-percent moisture level to 79 pounds per cubic foot, which would amount to about 73 pounds after the removal of the filling sleeve. This procedure would eliminate handling of the block and would simplify closing and strapping the containers immediately after compression. Since the uncompressed fruit has a density of about 43 pounds per cubic foot, the volume reduction would be approximately 41 percent. Formation of a highly cohesive block is obviously not essential in this procedure, so compression could probably be carried out with zero dwell.

COMPRESSION OF SPRAY-DRIED WHOLE EGG POWDER

The spray-dried whole egg powder used in the compression experiments was procured from various commercial plants. It conformed to the Quartermaster Corps specifications in force during the course of the work. (See footnote 3, p. 2.) At the outset the tests were confined to material containing 5 percent moisture. At a later date specifications covering Army purchases were revised to require that the moisture content not exceed 2 percent. However, a large volume of powder at the 5-percent moisture level continued to be accepted in some markets, and consequently attempts were made to develop compression procedures for both types of material. Compression characteristics at the lower and higher moisture levels were found to be very different.

The compression characteristics of spray-dried whole egg powder can be best understood if it is borne in mind that the material consists of hollow punctured spheres with diameters ranging from about 20 to 100 microns and with a lipoid content in excess of 40 percent. These properties tend to result in entrapment of air within the block during compression. When considerable air is entrapped and compressed within the material the blocks tend to "explode", or crack, as soon as pressure is released from the dies. Blocks containing even slight cracks cannot be subjected to the required handling without falling apart. Therefore, compression must be carried out under conditions that minimize occlusion of air.

The design of the mold was found to have considerable influence on compression results, and consequently various types were tested. These were as follows:

1. Plain nonfloating mold, with plane-faced interior walls. The mold box and lower die were held in fixed positions during compression.
2. Plain floating mold, also with the interior walls plane-faced. The form of construction permitted the mold box to float during compression—that is, when binding occurred at the wall surfaces the mold box moved with the material and thus equalized the force applied by the two mold dies.
3. Grooved nonfloating mold. Similar to the plain nonfloating mold except that vertical grooves, $\frac{1}{32}$ inch wide and $\frac{1}{16}$ inch deep, were machined in the walls of the mold box so as to facilitate escape of air. The grooves were spaced approximately ¾ inch apart. Clearance between die and walls was 0.007 inch.
4. Grooved floating mold. Similar to the plain floating mold except that the mold box was grooved. Clearance between die and walls was 0.007 inch.
5. Vacuum mold shown in figure 7 (p. 11). Of the nonfloating type; permitted evacuation of air from the mold box during compression. The air was withdrawn through $\frac{1}{64}$-inch holes machined in the faces of the mold dies. Each square inch of die face contained 45 holes. The clearance between dies and walls was 0.004 inch.

The procedures used experimentally to compress egg powder are briefly described and discussed in the following pages. Except where otherwise stated, these procedures had no significant effect on organoleptic quality or fluorescence as determined by Army specification methods. In addition the compressed material was easily reduced to a powder by hand, after which it was as readily reconstituted as the uncompressed material. In evaluating the effectiveness of the various compression procedures described below, it should be remembered that the bulk density of uncompressed egg powder is approximately 26 pounds per cubic foot.

Compression of Whole Egg Powder Containing 5 Percent Moisture

Compression of Blocks

Under suitable conditions it was found possible to form satisfactory blocks of 5-percent moisture content without heating or otherwise conditioning the material. One lot with a moisture content slightly below 5 percent responded satisfactorily when heated to 90° F. Powder containing 5 percent moisture does not flow freely at room temperature and therefore cannot be handled readily in automatic weighing equipment of conventional design. In view of this difficulty some compression experiments were conducted at −7° F. and at +35° F., temperatures at which the material is practically free flowing, but it was not found possible to form satisfactorily cohesive blocks at these low temperatures.

The pressure required to form acceptable blocks at room temperature was found to range from approximately 600 to 1,500 pounds per square inch. The value applicable in a given case depends principally on the moisture content of the material, the temperature, the type of mold employed, and the rate of compression. With a given set of conditions excessive pressure generally results in cracked blocks, whereas insufficient pressure results in poor cohesive quality. Blocks with a density of 50 pounds per cubic foot are satisfactorily cohesive if free of cracks, but when the density is only 3 or 4 pounds lower the compressed material lacks cohesiveness and tends to fall apart when handled.

Compression results, particularly when compressing is done at rapid rates, depend to a very great extent on the type of mold employed. Molds of the nonfloating type were found to have less tendency to form cracked blocks than those of the floating type. Apparently this is due to the former having less tendency during compression to seal at both ends and entrap air. The propensity of both types of molds to form cracked blocks was considerably reduced by grooving the interior walls of the mold box. The vacuum mold, as will be explained, gave better results than any other type.

Pressures ranging from 600 to 900 pounds per square inch were required to form satisfactory blocks at slow compression rates; that is, with nip, dwell, and clear periods of 10, 30, and 10 seconds, respectively. Pressures of about 1,000 pounds per square inch resulted in cracked blocks except in the vacuum mold. Blocks formed in the latter were sound even when compressed at 2,000 pounds per square inch, but oil began to be expressed from the powder at about 1,500 pounds per square inch. At the last-named pressure the final density of block was 57 pounds per cubic foot. The maximum density of block attainable with molds that are not evacuated is about 50 pounds per cubic foot.

Experiments in the formation of 4-ounce blocks in 2- by 3-inch molds showed that molds of the vacuum type are especially suited to compression at rapid rates. The vacuum mold gave satisfactory results at pressures of 1,000 to 1,500 pounds per square inch with nip, dwell, and clear periods of 2, 1, and 1 seconds, respectively. With the same dwell and clear, the grooved nonfloating mold required a nip period of 4 seconds for satisfactory results, whereas the grooved floating mold required a nip period of at least 10 seconds. In view of the long nip period required for the floating mold it is concluded that this type is not suited to the rapid compression of egg powder. This conclusion was verified by results obtained with the Baldwin Southwark press, which is also equipped with a grooved mold of the floating type. In this case the blocks weighed 1 pound, and sufficiently satisfactory results could not be obtained without resorting to the use of nip periods of at least 10 seconds and a dwell of 2 seconds.

Egg-powder blocks containing 5 percent moisture have only a slight tendency to expand after ejection from the mold, and it is not necessary to restrain them in holding presses. Expansion after ejection is 5 percent for the height dimension and 1 percent for the length and width dimensions. The blocks remain plane-faced on expanding. They should be wrapped as soon as possible after compression, and since the material is hygroscopic, long exposure to normal atmosphere should be avoided. Total expansion, based on dimensions while under pressure in the mold and dimensions after expansion, is approximately 2.5 percent in width and length and about 18 percent in height.

Compression in Cans

A few experiments were conducted to determine the feasibility of compressing egg powder directly in No. 2 cans. Bulging of the cans during compression was prevented by placing them in a close-fitting restraining mold made of wood. A sleeve that formed a part of the restraining mold was stationed above the top of the can and held a charge sufficient to fill the can with compressed material. Bulging of the indented bottom of the can was largely prevented by a loose-fitting metal plate of appropriate shape.

Powder containing 5 percent moisture attained a final density of 46 pounds per cubic foot when compressed in the cans at a pressure of 400 pounds per square inch with nip, dwell, and clear periods of 10, 30, and 10 seconds, respectively. With conditions otherwise identical a pressure of 1,000 pounds per square inch resulted in a final density of 54 pounds per cubic foot. Initial densities were somewhat higher but decreased because of the vertical expansion of the material after pressure was released. Total vertical expansion after release of pressure was approximately 7 percent. Application of a pressure of 1,000 pounds per square inch resulted in slight bulging of the indented base of the can immediately after pressure was released. This response was due to the frictional force developed between the compressed powder and the can walls. It would appear that such bulging could be avoided by employing a restraining mold that will hold the base plate firmly against the can for a second or two after pressure is removed from the ram.

The equipment available did not permit a study of compression in cans at rapid rates, but results of block compression experiments indicate that compression with short nip and dwell periods may be feasible. Possibly a vacuum ram, similar to the male die employed in the vacuum mold, would be useful in preventing excessive air entrapment during rapid compression.

Debulking by Jolting, Vibrating, and Tamping

Methods of increasing density by jolting, vibrating, and tamping powders at the 5-percent moisture level were briefly studied.

The jolting procedure consisted in dropping a can of loose powder 100 times onto a steel plate. The diameter of the can was 3¼ inches, the height of fill was approximately 6 inches, and the distance of fall was 2 inches. Contraction of volume practically ceased when the container had been dropped 75 times. Powders ranging in moisture content from 4.2 to 5.0 percent attained final densities of approximately 35 pounds per cubic foot as a result of this procedure.

Vibration of cans packed as described proved to be less effective than jolting. The filled cans were placed on a platform which was vibrated 60 times per second with an amplitude of approximately one-sixteenth inch. The powders were vibrated until no further reduction in volume occurred, which required about 4 minutes. Contraction of volume ceased when a bulk density of approximately 29 pounds per cubic foot was reached. It may be that slower rates of vibration and other amplitudes would be more effective than those applied in the tests, but the equipment to test this possibility was not available.

Debulking by hand tamping in a No. 10 can resulted in a final bulk density of 37 pounds per cubic foot. The material was added in successive 3-inch layers and tamped with a 2-pound cylinder 3 inches in diameter until volume was fairly constant. Since this procedure requires several minutes, it is considered to be impractical.

COMPRESSION OF WHOLE EGG POWDER CONTAINING 2 PERCENT MOISTURE

Work on the development of compression procedures for egg powder containing 2 percent moisture was mainly restricted to material obtained by vacuum drying high-quality commercial material containing 5 percent moisture. Material obtained in this manner conformed to Quartermaster Corps specifications. Drying the powder in a vacuum to a moisture content of 2 percent was necessary because it was found that commercial plants could not at first produce a spray-dried product that would meet the specification requirements for flavor and low moisture content. Later, when the compression studies had been discontinued, it was reported that a number of commercial plants had successfully solved the problems involved and had produced large quantities of specification material.

The physical properties of loose egg powder containing 2 percent moisture are similar to those of powder at the 5-percent moisture level in that the bulk density of the material is about 26 pounds per cubic foot, the powder is somewhat greasy, and the particles cling together in such a manner that the material will not flow freely. However, compression characteristics differed considerably. The procedures required to produce a satisfactory product of high density are more complex for the 2-percent powder than for the 5-percent.

Compression of Blocks

It was not found possible to compress 2-percent powder into satisfactory blocks at room temperature. Compression was attempted with very long nip, dwell, and clear periods and with various pressures in the range of 800 to 5,000 pounds per square inch, but in all instances the cohesiveness of block was insufficient to permit handling. Exudation of oil from the powder was considerable at about 3,000 pounds per square inch and was definitely excessive at still higher pressures.

Blocks of suitable cohesive quality were obtained only when the material was heated, but even under the most favorable conditions the strength of block was considerably less than that of blocks of powder containing 5-percent moisture and was insufficient to permit rough handling. With the 2-percent-moisture material heated to temperatures of 125° and 150° F. and compressed in a nonfloating mold with nip, dwell, and clear periods of 10, 30, and 10 seconds, respectively, the pressure required to form acceptable blocks was found to be between 800 and 1,200 pounds per square inch. Final density of block was approximately 50 pounds per cubic foot, and the tendency to expand was about the same as for blocks with 5-percent moisture. Block cohesiveness was considerably better at the higher temperature than at the lower.

The vacuum mold enabled acceptable blocks to be formed at somewhat lower temperatures. For example, with nip, dwell, and clear periods as noted, fair blocks were obtained with material heated to 100° F. and at pressures in the range of 1,500 to 2,000 pounds per square inch. The pressures required were about 500 pounds per square inch lower and block cohesiveness was improved when the vacuum mold was employed with material heated to 125° and 150° F. This mold was also found to give satisfactory results in compressing 4-ounce blocks at rapid rates. That is, it was found possible to compress with nip, dwell, and clear periods of 2 seconds, 1 second, and 1 second, respectively, when the material was heated to 150° F. Molds that were not provided with means for evacuation of air did not give satisfactory results at rapid rates of compression.

The blocks formed from 2-percent material ranged in weight from 4 ounces to 1 pound. The time required to cool 1-pound, cellophane-wrapped blocks measuring approximately 3 by 5 by 2⅓ inches from 150° to 85° F. by natural convection at an ambient temperature of 77° F. was 180 minutes. Blocks weighing 4 ounces (dimensions, 2 by 3 by 1.4 inches) cooled to the same temperature in 70 minutes under similar conditions. Since it is well known that the quality of egg powder is adversely affected by prolonged exposure to elevated temperatures, it would seem advisable to employ cooled contact plates or rapidly moving cool air to accelerate cooling of blocks. Even with these expedients, however, it may be that the rate of cooling would be too slow to justify the formation of very large blocks. It was found that organoleptic quality is not adversely affected when the time required to cool to room temperature is 70 minutes. Possibly a longer cooling time can be tolerated, but tests were not undertaken to determine what the maximum time might be.

Some attempts were made to improve block cohesiveness by blending the powder with materials such as wheat-germ flour and oat flour. These materials were added in 5-percent amounts to the egg powder. They were found to improve block strength considerably and to have no immediate effect on organoleptic quality. However, retention of flavor during storage was considerably poorer for the compressed blends than for compressed unadulterated powder of the same moisture content, and consequently it was concluded that the use of these materials as binders is inadvisable.

Drying Compressed Blocks

As previously mentioned, it was not found possible to form blocks of 2-percent powder at rapid compression rates except in a vacuum mold. Molds of this type obviously incur considerably more expense than those of conventional designs. Moreover, there is some question as to just how a vacuum mold suited to commercial operation should be designed. Consequently, one other possible means of securing satisfactory blocks was investigated. This consisted in compressing blocks of 5-percent-moisture material, which is relatively easy to compress, and then drying the blocks to the specification moisture level. The experiments showed that satisfactory results can be obtained with this procedure. However, the method is not to be taken as an ideal solution to the problem, since the cost of drying would be appreciable.

In the tests the 5-percent-moisture material was compressed into 1-pound blocks and then wrapped in thin kraft paper and sealed with gummed tape. The wrapped blocks measured approximately 3 by 5 by 2½ inches and had a density of 50 pounds per cubic foot. Drying was carried out in a vacuum shelf drier at an absolute pressure of 4 millimeters of mercury and with shelves maintained at 158° F. The wrapped blocks were placed in the drier with one 3- by 5-inch face in contact with the heated shelf. Under these conditions the material dried to the specification moisture content (2 percent) in 4 hours. Organoleptic evaluation after drying showed that the material conformed in all respects to the current Quartermaster Corps specification requirements and that the quality of the powder was not adversely affected during drying.

The wrapped dried blocks had densities of approximately 48 pounds per cubic foot and were equal in appearance and handling quality to the original undried blocks. When unwrapped they were found to contain several irregular cracks which undoubtedly were produced by stresses set up during drying. The blocks broke readily into lumps which were sufficiently friable to be crumbled to a powder with the fingers.

Compression in Cans

Tests involving compression of 2-percent-moisture powder directly in cans were conducted exactly as described for material at the 5-percent-moisture level.

For compression at room temperature with nip, dwell, and clear periods of 10, 30, and 10 seconds, respectively, and a pressure of 1,000 pounds per square inch, the final density of the material within the cans was 46 pounds per cubic foot. With conditions otherwise identical, a pressure of 600 pounds per square inch resulted in a final density of 40 pounds per cubic foot.

All things considered, it seems that direct compression in the final container is the most practical method of increasing the density of powder at the 2-percent-moisture level. This method makes it unnecessary to heat the material, since the product need not be very cohesive, and also eliminates a number of other steps that are required in the formation of blocks. Compression of the material in rigid paper containers would appear to be a possibility. This would, of course, require the development of special restraining molds and possibly the use of a sleeve insert to protect the package during compression.

Debulking by Jolting and Vibrating

Methods of increasing density by jolting and vibrating 2-percent-moisture powder were briefly tested by procedures identical with those discussed in connection with tests on powder containing 5 percent of moisture.

The jolting procedure resulted in densities ranging from 29 to 36 pounds per cubic foot, depending on the particular powder treated. Results obtained in repeated trials with a given powder were consistent, and the final density was not materially affected by moderate change in moisture content or by considerable change in temperature. The variation in density for different lots appeared to be due to differences in the size and shape of the powder particles.

The previously described vibrational method of packing proved to be ineffectual. The density attained was only 24 pounds per cubic foot. Since higher densities were obtained by jolting the can very slightly while filling, it was evident that vibration was causing the material to occlude air and that the rate of vibration obtained with the equipment at hand was not suitable.

RESULTS OF COMPRESSION TESTS ON CEREAL AND SOYA FLOURS

Cereal and soya flours subjected to compression tests included white flour, whole-wheat flour, and full-fat and expeller types of soya flour. These compression tests were concerned with the formation of small sample blocks for use in preliminary storage studies and not with the idea of the development of commercially practicable compression procedures. Thus the results of tests here summarized give only a preliminary view of what can be expected from these products, and considerable further work will be required to determine the optimum conditions for compression.

A white flour termed "bakers' long patent flour" was used in the tests. Commercially milled from hard wheat, this flour was found to be of good bread-baking quality. It contained 15.5 percent protein, 0.57 percent ash (both on a moisture-free basis), and 13.1 percent moisture. Part of the sample was raised in moisture to 14.3 percent by storage in a high-humidity chamber. The whole-wheat flour was milled from hard red spring wheat in an experimental milling unit and contained 16.5 percent protein, 1.97 percent ash (both on a moisture-free basis), and 13.6 percent moisture. The freshly milled flour produced a satisfactory loaf of bread. The soya flours used in the tests were of commercial manufacture. The full-fat soya flour contained 43.5 percent protein, 24.8 percent fat, 2.1 percent crude fiber (all on a moisture-free basis), and 6 percent moisture. The expeller-type flour contained 53.7 percent protein, 7 percent fat, 2.6 percent crude fiber (all on a moisture-free basis), and 4.8 percent moisture.

The white, whole-wheat, and soya flours were compressed into small disks weighing 2 to 5 ounces by a small hand-operated Carver hydraulic press. Two pressures, 1,800 and 3,200 pounds per square inch, were used. The compressions were made at room temperature with a dwell of approximately 1 minute. Approximate densities before and after compression are given in table 17.

The blocks of white flour were fairly cohesive. Those containing 14.3 percent moisture were somewhat more cohesive than those at the lower moisture level. The blocks withstood handling without crumbling but could be crushed fairly easily in the hands. The compressed flour blocks entered readily without grinding or sieving into a uniform dough mix when subjected to the usual bakery procedures for bread making. The results of bread-baking tests, measured by loaf volume, grain texture, and crumb color,

Table 17.—*Densities of different kinds of flours compressed at two pressures and uncompressed*

Material	Densities obtained at pressures (in pounds per square inch) of—		
	0	1,800	3,200
	Pounds per cubic foot	*Pounds per cubic foot*	*Pounds per cubic foot*
White flour, 13.1 percent moisture	29	47	55
White flour, 14.3 percent moisture	27	45	52
Whole-wheat flour	29	47	51
Soya flour (full fat)	23	54	59
Soya flour (expeller)	27	56	59

presented no evidence to indicate that compression as applied in these experiments injured or otherwise affected the quality of the flour for bread making. Further reference to these tests will be made later in discussing the results of storage experiments on the compressed and uncompressed samples.

The blocks of whole-wheat flour were considerably less cohesive than those prepared from white flour, and it was necessary to handle them with care to avoid crumbling. The results of bread-baking tests, which are discussed later, showed no difference in the baking quality of the compressed and uncompressed flours.

Compressed expeller soya flour was slightly more cohesive than compressed whole-wheat flour and handled satisfactorily. The blocks of full-fat soya flour, however, were excessively cohesive. Mechanical means for breaking them up and probably sieving would be required in order to obtain satisfactory reconstitution. The results of storage tests on samples of the uncompressed and compressed soya flours will be summarized later.

SUMMARY OF COMPRESSION CONDITIONS FOR SPECIFIC FOODS AND VOLUME REDUCTIONS EFFECTED BY COMPRESSION

Summarized data are given in table 18, which lists the general range of conditions found applicable for each commodity, the densities before and after compression, and the volume reductions resulting from compression. The sets of conditions found most suited to production work with the equipment at hand are also given, together with the approximate block density believed optimum for each product. Data relating to cereal and soya flours are not included in this table because considerable further work will be required to determine fully the compression characteristics of these flours.

STORAGE BEHAVIOR OF COMPRESSED FOOD PRODUCTS

As already pointed out, it was not possible to accumulate comprehensive data on the relation between compression and storage life, and much further work remains to be done on this subject. The results of such tests as it was possible to conduct in the time available are reviewed below.

Carrots

Packs of uncompressed and compressed dehydrated diced carrots were prepared from material of good quality containing 5 percent moisture and stored in sealed cans at 90° F. for 32 weeks. The blocks were compressed at 900 pounds per square inch, 160° F., with a 30-second dwell; density of block was 63 pounds per cubic foot. The packs were 220 grams for the uncompressed and 410 grams for the compressed in a No. 2 can, which corresponds to 17 pounds of uncompressed and 32 pounds of compressed product in a 5-gallon can. Three sets of samples, each consisting of compressed and uncompressed packs, were prepared. One set was packed by sealing in air, another was sealed at an absolute pressure of 2 inches of mercury, and another was gas-packed by evacuating and gassing with carbon dioxide in such a way as to obtain a package atmosphere containing approximately 1 percent of oxygen. Organoleptic quality and carotene determinations were conducted immediately and after 16 and 32 weeks of storage.

The results of the determinations indicated that compression had no significant effect on initial quality and that the storage behavior of all gas- and vacuum-packed samples was practically identical regardless of whether the material was loose or compressed. For these samples organoleptic quality decreased from an initial rating of "good" to a rating of "fair" after 16 weeks of storage at 90° F., and to "fair to poor" after 32 weeks. Retention of carotene in the air-packed samples was considerably greater for the compressed carrots than for the uncompressed. However, carotene retention for the air-packed products was not nearly as satisfactory as for those that were gas- or vacuum-packed. Because of this behavior organoleptic tests were not conducted on the air-packed samples.

Egg Powder

Investigations of the storage life of egg powder showed that the rate of loss of quality of 5-percent-moisture powder during storage is substantially the

Table 18.—*Summary of conditions found applicable in compressing specific foods, and volume reductions effected by compression* [1]

Food	Form	Moisture content	Temperature	Maximum pressure [2]	Dwell [2]	Density before compression [3]	Cooling conditions or post-compression treatment	Final density of block	Percentage volume reduction [4]
		Percent	°*F.*	*Pounds per square inch*	*Seconds*	*Pounds per cubic foot*		*Pounds per cubic foot*	
Beets	Diced, stripped, or sliced	3.5–5.5	140–160	650–1,500	0–60	12.5–25.0	Holding press	55–75	55–83
	Diced	*4.6*	*150*	*1,200*	*0*	*25*	do	*65*	*62*
Cabbage	Shredded	3.5	140–160	200–5,500	0–60	10.5	do	50–70	79–85
	do	*3.5*	*150*	*2,250*	*3*	*10.5*	do	*60*	*83*
Carrots	Diced, stripped, or sliced	3.7–5.2	150–160	650–4,000	3–60	10.6–18.7	do	49–70	62–85
	Diced	*4.5*	*150*	*4,000*	*3*	*18.7*	do	*65*	*71*
Onions	Flaked	3.0–4.0	120–150	250–1,500	0–60	6.2–11.9	do	40–70	70–91
	do	*4.0*	*130*	*700*	*0*	*11.9*	do	*50*	*76*
Potatoes [5]	Diced or stripped	[6] 9.0–15.0	140–160	200–2,000	3–60	15–23	do	50–60	54–75
	Diced (low sugar content)	[6] *14*	*150*	*800*	*3*	*23*	do	*50*	*54*
Rutabagas	Diced or sliced	5.5–6.9	150–160	450–5,500	0–60	11–28	do	50–75	44–85
	Diced	*5.6*	*150*	*5,500*	*0*	*28*	do	*65*	*57*
Sweetpotatoes [7]	Diced (Porto Rico)	4.0–6.6	140–160	1,000–5,500	3–30	27	do	60–70	55–61
	do	*6.1*	*150*	*3,000–4,000*	*3–15*	*27*	do	*65*	*58*
Apples	Nuggets	1.3–2.1	120–130	100–4,000	0–30	18–21	do	29–75	27–76
	do	*1.8*	*130*	*1,200*	*0*	*20*	do	*65*	*61*
Apricots	Halves	13.2–18.7	(8)	100–900	15	35	Boxed	55–85	36–59
	do	*13.2*	(8)	*300*	*15*	*35*	do	*75*	*53*
Cranberries [9]	Whole	5.5	150	400–2,000	5–30	12.7	Holding press	40–60	68–79
	do	*5.5*	*150*	*2,000*	*5*	*12.7*	do	*55*	*77*
Peaches	Halves	10.7	(8)	300–600	30–60	36	Boxed	58–80	38–55
	do	*10.7*	(8)	*300*	*30*	*36*	do	*73*	*51*
Prunes [9]	Whole	12.4	(8)	300–600	30–60	43	do	70–80	38–46
	do	*12.4*	(8)	*300*	*30*	*43*	do	*73*	*41*
Egg powder [9]	Spray-dried	5	65–90	600–1,500	1–30	26	Wrapped	47–53	45–51
	do	*5*	(8)	*700–1,000*	*1*	*26*	do	*50*	*48*
	do	2	(8)	*1,000*	*30 or less*	*26*	Compressed in cans	*46*	*43*

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[1] Of the conditions imposed in the experiments, those indicated by italic figures appear to be the most suitable for production work. Much shorter dwells than indicated may be applicable with specially designed equipment, particularly for dehydrated apricots, peaches, and prunes.

[2] Where ranges of pressures and dwells are indicated, the higher pressure is used at the shorter dwell and the lower pressure at the longer dwell.

[3] Bulk density depends mainly on form; stripped and sliced forms are always considerably lower in density than diced material.

[4] From density before compression and final density.

[5] Further study is required to develop satisfactory procedure; see text. Conditions noted are tentative.

[6] Blocks are dried to specification moisture level (7 percent) after compressing.

[7] Figures apply to moist types only. Compression data are incomplete for dry types.

[8] Room temperature.

[9] See text for alternative methods.

same whether the material is loose or compressed into blocks with a density of approximately 50 pounds per cubic foot. In this work the uncompressed powders were air-packed in hermetically sealed containers. The compressed blocks were tightly wrapped in waxed paper and then dipped in melted paraffin wax until a thick continuous coating of wax was formed. The compressed and uncompressed powders were stored at 98° F. for periods of 2, 4, 8, and 16 weeks. Organoleptic tests were employed in determining changes in quality during storage.

Recently revised Army specifications call for egg powder containing 2 percent moisture, but it was not possible in the time available to determine the effect of compression on storage behavior at this lower moisture level.

ROLLED OATS

Twenty-ounce compressed samples of rolled oats, commercially packed in cans, and comparable uncompressed samples were stored for different periods up to 36 weeks, at temperatures of 32°, 70°, 90°, 110°, and 130° F. The rolled oats used were known as white quick-cooking oats and contained approximately 7 percent moisture.

When grains or other seeds or their milled products containing appreciable quantities of fat undergo deterioration during storage the most significant readily measurable chemical change in the product is usually an increase in its content of free fatty acids resulting from hydrolysis of the fat. In these studies, therefore, "fat acidity," defined as the number of milligrams of potassium hydroxide required to neutralize the free fatty acids in 100 grams of product (calculated to a moisture-free basis), is used as one of the criteria of deterioration. Tests for fat acidity and changes in organoleptic quality were made at intervals of 4, 8, 12, 24, and 36 weeks. The fat acidity values are shown in table 19.

There was a slow, progressive increase in fat-acidity values as the storage period was lengthened, and the change was slightly more rapid in the uncompressed samples. Highest figures were obtained in the compressed samples stored at 130° F. for 24 to 36 weeks.

No off color or flavor could be detected in any of the samples, even those stored at the highest temperature. The high antioxidant properties of certain constituents of the oat grain may account in part for the high keeping quality of this product.

From these findings it appears that rolled oats are well adapted to compression and may be stored for appreciable lengths of time at ordinary temperatures without material change in quality.

TABLE 19.—*Results of fat-acidity determinations on samples of compressed and uncompressed rolled oats stored at various temperatures and sampled at intervals up to 36 weeks*

Storage period (weeks)	Storage temperature	Fat-acidity values [1]	
		Compressed	Uncompressed
	° F.		
0	32	52	61
4	32	57	58
	70	53	57
	90	52	56
	110	50	62
	130	61	67
8	32	59	64
	70	64	65
	90	64	74
	110	63	76
	130	76	106
12	32	55	68
	70	60	74
	90	62	78
	110	69	76
	130	85	103
24	32	55	51
	70	58	72
	90	64	73
	110	75	96
	130	133	96
36	32	56	60
	70	66	67
	90	76	82
	110	112	103
	130	236	112

[1] Expressed in milligrams of potassium hydroxide required to neutralize the free fatty acids in 100 grams of sample (moisture-free basis).

SOYA FLOURS

Samples of expeller and full-fat soya flours compressed into small blocks at pressures of 1,800 and 3,200 pounds per square inch, together with uncompressed samples of the same flours, were stored in tight containers at 70° and 90° F. for 60 weeks and at 110° F. for 37 weeks. The stored samples were examined at intervals and analyses were made to determine the effect of compression on their storage behavior under the conditions named. Fat-acidity changes were used as the criteria.[7] The findings are given in table 20.

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[7] Fat acidity is a measure of hydrolytic deterioration of a fat or fatty oil which results in the liberation of free fatty acids and glycerin. Since in the oil of the soybean the fatty acids are of the higher molecular weight type and are essentially odorless and tasteless, the development of high fat-acidity values does not necessarily result in recognized off flavor.

TABLE 20.—*Results of storage tests on compressed and uncompressed soya flours held at 70°, 90°, and 110° F. for various periods, in terms of fat-acidity values*

Flour type	Storage period	Storage temperature	Fat-acidity values [1] of samples compressed at pressures (in pounds per square inch) of—		
			0	1,800	3,200
	Weeks	° *F.*			
Full-fat, 4.3 percent moisture	0	70	30	......	......
		90	30	......	......
	9	70	27	26	23
		90	27	27	22
	16	70	32	26	28
		90	29	28	30
	23	70	31	29	31
		90	31	33	35
	48	70	35	35	35
		90	33	33	34
	60	70	46	41	43
		90	35	37	36
Full-fat, 5.4 percent moisture	0	110	29	......	......
	3	110	44	52	48
	25	110	119	110	102
	37	110	126	116	132
Expeller, 4.8 percent moisture	0	70	18	......	......
		90	18	......	......
	9	70	19	16	17
		90	22	23	29
	16	70	25	30	32
		90	20	24	25
	23	70	26	25	28
		90	26	34	28
	48	70	28	28	25
		90	39	41	42
	60	70	44	39	47
		90	35	45	45
Expeller, 6 percent moisture	0	110	16	......	......
	3	110	23	24	24
	25	110	37	34	46
	37	110	46	42	57

[1] Expressed in milligrams of potassium hydroxide required to neutralize the free fatty acids in 100 grams of sample (moisture-free basis).

No significant differences were observed between the fat-acidity values of the compressed and the uncompressed soya flours of either type when stored for 60 weeks at 70° and 90° F. There was a progressive slight increase in fat acidity of the uncompressed and compressed samples of the expeller flour that were stored at 110° F., but the values were still low at the end of 37 weeks' storage. The samples of full-fat soya flours stored under the same conditions showed a considerable increase in fat acidity during the period, but there were no material differences in the fat-acidity values for the compressed and uncompressed samples.

In view of these results it appeared that compression had no material influence on the storage behavior of the soya flours.

CHEESE-SOYA SOUP

One-pound samples of cheese-soya soup, commercially compressed into bricks and wrapped in heavy waxed paper, were stored in tight containers with lots of the unpressed soup at five temperatures, 32°, 70°, 90°, 110°, and 130° F. All samples were stored in sealed cans for 24 weeks except those stored at 130° F., which were discarded after 8 weeks because of advanced deterioration. The soup powder had 9.7 percent moisture and 12 percent fat and contained the following ingredients:

	Percent
Dehydrated cheese (mixture of Parmesan and American Cheddar)	25
Nonfat dry milk solids	10
Dry whey	5
Soya flour	25
Wheat flour	30
Salt and seasoning	5

The results of the chemical and other tests are given in table 21.

These results show that from the standpoint of fat-acidity development the compressed samples possessed somewhat better storage properties than the uncompressed. As was to be expected, progressively higher acidity values were obtained as storage temperature levels were increased, and the rate of increase was higher for the uncompressed samples. From the standpoint of organoleptic quality there was little difference in the storage behavior of the compressed and uncompressed soups.

At the storage temperature of 32° F. very little change was noted in the compressed and uncompressed samples during the 12 weeks of storage. There was a small increase in fat acidity after 8 weeks, but even in the uncompressed samples this was not marked and was not reflected in any noticeable change in organoleptic quality. At 70° F. also there was no marked alteration in appearance or flavor at the end of 12 weeks of storage.

Neither the compressed nor the uncompressed samples stored at 90° F. showed any outstanding change during the first 4 weeks, but a slight falling off in quality was noted after 8 weeks. At the end of 12 weeks a slight alteration in color and an off odor were observed, and in consequence the flavor of the samples graded slightly under "good."

Compressed samples stored at 110° F. remained unchanged in appearance and organoleptic quality for 2 weeks, but at the end of 3 weeks slight browning had occurred and there was a slightly burned odor. The soup was still rated as "good" in flavor. In 4 weeks the discoloration had increased materially and

TABLE 21.—*Changes in fat acidity and table quality in compressed and uncompressed cheese-soya soup stored at different temperatures for different periods of time*

Storage period (weeks)	Quality factors [1]	Stored at—32° F.		70° F.		90° F.		110° F.		130° F.	
		Compressed	Uncompressed	Compressed	Uncompressed	Compressed	Uncompressed	Compressed	Uncompressed	Compressed	Uncompressed
0	Fat acidity	65	61								
	Color	LY	LY								
	Odor	N	N								
	Flavor	5.0	4.8								
	Consistency	4.4	4.4								
	General acceptability	4.8	4.4								
1	Fat acidity	62	68	65	71	67	79	71	82	93	91
	Color	LY	LY	LY	LY	LY	LY	LY	LY	SBC	SBC
	Odor	N	N	N	N	N	N	N	N	N	N
	Flavor	5.0	4.8	4.9	4.8	4.7	4.7	4.8	4.3	3.3	3.1
	Consistency	4.9	4.8	4.9	4.6	4.7	4.5	4.9	3.7	4.4	4.2
	General acceptability	5.0	4.9	4.9	4.8	4.8	4.7	4.8	4.4	3.0	2.9
2	Fat acidity	63	69	68	77	75	90	81	103	90	118
	Color	LY	LY	LY	LY	LY	LY	LY	LY	DB	DB
	Odor	N	N	N	N	N	N	N	N	Bu	Bu
	Flavor	4.8	4.9	4.8	4.6	4.8	4.3	4.8	4.3	1.3	1.3
	Consistency	4.7	4.9	4.9	4.3	4.6	4.0	4.7	4.2	4.0	3.1
	General acceptability	5.0	5.0	4.9	4.5	4.8	4.3	4.8	4.1	1.5	1.0
3	Fat acidity	62	67	70	80	79	100	90	121	101	135
	Color	LY	LY	LY	LY	LY	LY	SB	SB	DB	DB
	Odor	N	N	N	N	N	N	SBu	SBu	Bu	Bu
	Flavor	5.0	4.8	4.6	4.7	4.8	4.4	4.0	3.2	1.7	1.4
	Consistency	5.0	4.2	4.7	4.2	5.0	4.3	4.8	4.8	3.5	3.3
	General acceptability	5.0	4.7	4.6	4.5	4.7	4.3	4.0	3.0	1.5	1.3
4	Fat acidity	63	68	72	91	86	113	97	139	108	158
	Color	LY	LY	LY	LY	LY	LY	Br	Br	DB	DB
	Odor	N	N	N	N	N	N	SBu	SBu	Bu	Bu
	Flavor	4.9	5.0	4.9	5.0	4.7	4.8	3.8	3.5	1.0	1.0
	Consistency	4.8	4.0	4.9	4.0	4.9	4.8	4.6	4.3	4.1	3.8
	General acceptability	4.9	4.8	4.9	4.8	4.6	4.7	3.5	3.3	1.3	1.0
8	Fat acidity	69	83	92	129	109	168	125	180	142	189
	Color	LY	LY	LY	LY	LY	LY	Br	Br	DB	DB
	Odor	N	N	N	N	N	N	SBu	SBu	Bu	Bu
	Flavor	5.0	5.0	4.9	4.8	4.3	4.0	2.5	2.2	1.3	1.0
	Consistency	4.4	4.5	4.8	4.5	5.0	4.3	4.0	4.3	3.3	4.0
	General acceptability	5.0	5.0	4.9	4.7	4.4	3.8	2.4	2.3	1.3	1.2
12	Fat acidity	68	76	91	130	124	176			(2)	(2)
	Color	LY	LY	LY	LY	PY	PY				
	Odor	N	N	N	N	Off	Off				
	Flavor	5.0	4.8	5.0	4.7	3.8	4.5	1.6	2.0		
	Consistency	5.0	4.5	5.0	4.7	4.4	5.0	3.5	4.0		
	General acceptability	5.0	4.8	5.0	4.7	3.8	4.2	1.8	2.2		

[1] Fat acidity is expressed in milligrams of potassium hydroxide required to neutralize the free fatty acids in 100 grams of sample (moisture-free basis).

Color changes are indicated by the symbols Br, brown; DB, dark brown; LY, light yellow; PY, pale yellow; SB, slightly brown; SBC, slightly brown cream.

Odor changes are indicated by the symbols Bu, burned; N, normal; and SBu, slightly burned.

Flavor, consistency, and general acceptability values represent the average ratings given by a tasting panel of 5 judges: 5.0, very good; 4.0, good; 3.0, fair; 2.0, poor; and 1.0, very poor.

[2] Discarded because of advanced deterioration.

a distinct falling off in organoleptic quality was noted. Further storage resulted in marked deterioration, and in 12 weeks the flavor was "poor." The changes in fat acidity were somewhat more rapid in the uncompressed samples.

The storage temperature of 130° F. proved entirely unsatisfactory, a distinct falling off in appearance and flavor being observed within a week. In 2 weeks both compressed and uncompressed samples graded "poor" to "very poor."

PEA-SOYA SOUP

Five-pound samples of pea-soya soup, commercially compressed into bricks, packaged in cardboard, and wrapped in heavy waxed paper, were stored in tight containers with lots of the unpressed soup at

TABLE 22.—*Changes in fat acidity and table quality in compressed and uncompressed pea-soya soup stored at different temperatures for different periods of time*

Storage period (weeks)	Quality factors [1]	Stored at—									
		32° F.		70° F.		90° F.		110° F.		130° F.	
		Compressed	Uncompressed	Compressed	Uncompressed	Compressed	Uncompressed	Compressed	Uncompressed	Compressed	Uncompressed
0	Fat acidity	21	26	...	...	...	...	...	...	...	...
	Color	LG	LG	...	...	...	...	...	...	...	...
	Odor	N	N	...	...	...	...	...	...	...	...
	Flavor	4. 0	4. 1	...	...	...	...	...	...	...	...
	Consistency	4. 6	4. 6	...	...	...	...	...	...	...	...
	General acceptability	4. 0	4. 5	...	...	...	...	...	...	...	...
1	Fat acidity	23	25	32	24	37	29	47	33	46	34
	Color	LG	LG	LG	LG	LG	LG	LG	LG	RG	RG
	Odor	N	N	N	N	N	N	N	N	N	N
	Flavor	4. 6	4. 8	4. 8	4. 4	4. 4	5. 0	3. 8	4. 4	3. 1	3. 3
	Consistency	5. 0	5. 0	5. 0	5. 0	5. 0	5. 0	5. 0	5. 0	5. 0	4. 6
	General acceptability	4. 8	4. 9	4. 6	4. 4	4. 1	4. 9	3. 8	4. 5	2. 5	3. 0
2	Fat acidity	21	25	36	22	46	25	55	32	54	33
	Color	LG	LG	LG	LG	LG	LG	LG	LG	RG	RG
	Odor	N	N	N	N	N	N	N	N	SH	SH
	Flavor	4. 9	4. 9	4. 4	4. 5	4. 8	5. 0	4. 1	3. 9	3. 0	2. 3
	Consistency	5. 0	4. 8	5. 0	4. 9	5. 0	5. 0	4. 6	4. 9	4. 6	4. 3
	General acceptability	4. 8	4. 7	4. 5	4. 4	4. 8	4. 9	4. 0	3. 8	3. 1	2. 6
3	Fat acidity	21	25	34	24	47	27	66	33	63	38
	Color	LG	LG	LG	LG	LG	LG	LBG	BG	SB	DB
	Odor	N	N	N	N	N	N	SH	SH	H	H
	Flavor	5. 0	5. 0	4. 7	4. 7	4. 8	4. 9	4. 0	3. 8	2. 6	2. 6
	Consistency	5. 0	5. 0	4. 7	4. 9	4. 9	4. 9	4. 9	4. 9	4. 6	4. 6
	General acceptability	5. 0	5. 0	4. 9	4. 9	4. 7	4. 7	4. 1	3. 9	1. 8	2. 1
4	Fat acidity	20	25	35	23	59	27	80	34	[2] 68	38
	Color	LG	LG	LG	LG	LG	LG	SB	SB	DB	DB
	Odor	N	N	N	N	N	N	SH	SH	H	H
	Flavor	4. 8	5. 0	5. 0	4. 5	4. 3	4. 6	3. 9	3. 9	2. 5	1. 9
	Consistency	5. 0	5. 0	5. 0	5. 0	5. 0	4. 9	4. 9	4. 9	4. 2	2. 5
	General acceptability	5. 0	5. 0	4. 7	4. 6	4. 3	4. 6	3. 8	3. 6	1. 7	1. 6
8	Fat acidity	23	23	48	27	64	37	116	55	[2] 60	54
	Color	LG	LG	LG	LG	LG	LG	SB	SB	DB	DB
	Odor	N	N	N	N	N	N	SH	SH	Bu	Bu
	Flavor	4. 7	4. 9	4. 3	4. 6	4. 3	4. 2	3. 0	3. 3	1. 8	1. 8
	Consistency	5. 0	4. 9	4. 4	4. 9	4. 9	4. 7	4. 1	4. 2	2. 9	2. 8
	General acceptability	4. 8	4. 9	4. 2	4. 7	4. 1	4. 1	2. 9	3. 3	1. 4	1. 4
12	Fat acidity	27	33	70	37	107	52	143	65	(3)	(3)
	Color	LG	LG	LG	LG	YB	YB	Br	Br		
	Odor	N	N	N	N	SH	SH	H	H		
	Flavor	5. 0	4. 9	4. 3	4. 8	3. 9	3. 9	2. 4	1. 8		
	Consistency	4. 8	4. 8	4. 8	4. 9	4. 8	4. 8	4. 0	2. 7		
	General acceptability	5. 0	4. 8	4. 3	4. 7	4. 2	4. 1	2. 5	2. 0		
24	Fat acidity	31	25	101	49	174	70	201	91	(3)	(3)
	Color	LG	LG	YB	YB	YB	YB	Br	Br		
	Odor	N	N	N	N	H	H	Bu	Bu		
	Flavor	5. 0	4. 9	4. 5	4. 8	3. 4	3. 8	2. 0	1. 5		
	Consistency	5. 0	5. 0	5. 0	5. 0	4. 8	4. 8	3. 3	3. 1		
	General acceptability	5. 0	4. 9	4. 8	4. 8	3. 4	3. 9	2. 3	1. 9		

---

[1] Fat acidity is expressed in milligrams of potassium hydroxide required to neutralize the free fatty acids in 100 grams of sample (moisture-free basis).

Color changes are indicated by the symbols BG, brown green; Br, brown; DB, dark brown; LBG, light brown green; LG, light green; RG, red green; SB, slightly brown; and YB, yellow brown.;

Odor changes are indicated by the symbols Bu, burned; H, haylike odor; N, normal; SH, slight haylike odor.

Flavor, consistency, and general acceptability values represent the average ratings given by a tasting panel of 5 judges: 5, very good; 4, good; 3, fair; 2, poor; and 1, very poor.

[2] These samples lost moisture during storage.

[3] Discarded because of advanced deterioration.

the five temperatures of 32°, 70°, 90°, 110°, and 130° F. All samples were stored for 24 weeks except those stored at 130°, which were discarded after 8 weeks because of advanced deterioration. The pea-soya soup had 8.3 percent moisture and 2.5 percent fat and contained the following ingredients:

	Percent
Peas	50.0
Soya flour	25.0
Nonfat dry milk solids	10.0
Dried brewer's yeast	2.62
Hydrolized vegetable protein	4.0
Celery	.25
Pepper	.255
Salt	7.75
Garlic and seasonings	.125

The results of the chemical and other tests are given in table 22.

In the compressed pea-soya soup the fat acidity values became progressively higher as the storage temperatures and time periods were increased. Exceptions were samples stored at 130° F. for 4 and 8 weeks, which dried out owing to failure of the cardboard and waxed-paper wrappers to maintain a tight seal. Differences in moisture level are believed to have influenced the rate of chemical change in these cases. Fat-acidity changes were less marked in the uncompressed samples and did not proceed as rapidly as in the compressed material. The reason for this difference in storage behavior is not known. Aside from differences in fat-acidity values the compressed and uncompressed samples behaved fairly uniformly throughout the tests.

It is to be noted that at the storage temperature of 32° F. the fat-acidity values remained low, the color and odor normal, and the flavor very good in both the compressed and uncompressed samples during the entire 24 weeks of storage. At the storage temperature of 70° F. the color, odor, and flavor remained equal to that of the original material for 12 weeks. There was a slight color change after 24 weeks, but this was not pronounced and the flavor was good. At 90° F. the appearance, odor, and flavor remained good for 8 weeks. Beyond this period fat-acidity changes became marked, the color and odor were noticeably changed, and there was some falling off in flavor. The material was still "good," however, after 12 weeks of storage at this temperature; but at the end of 24 weeks the material graded only "fair."

At 110° F. changes in color and odor were noted after 3 weeks of storage, though the flavor was good. After 4 weeks there was some change in color, odor, and flavor. Longer storage at this temperature yielded inferior products. Storage at 130° F. proved entirely unsatisfactory. At the end of a week the flavor was only "fair," and longer storage resulted in increased rapid deterioration. The samples were discarded as unfit for human food after 8 weeks.

Samples of the commercially packed pea-soya soup, held in storage at the five different temperatures, were also tested for vitamin B_1 (thiamine) content. This study was made to determine the retention or loss of thiamine in the compressed and uncompressed pea-soya soup stored at the different temperatures for the various periods of time.

The results of the vitamin tests are given in table 23.

As the table shows, there was fairly close agreement between the compressed and uncompressed samples of pea-soya soup with respect to thiamine changes. At the storage temperatures of 32°, 70°, and 90° F. there was no appreciable loss in thiamine

TABLE 23.—*Vitamin B_1 (thiamine) content of pea-soya soup samples held at different storage temperatures for different periods of time* [1]

Storage temperature (°F.)	Micrograms of vitamin B_1 per gram after material was stored for (weeks)—															
	0		1		2		3		4		8		12		24	
	U [2]	C [2]	U	C	U	C	U	C	U	C	U	C	U	C	U	C
32	6.8	6.8	6.9	6.9	7.1	7.1	6.6	6.3	7.3	6.7	6.6	7.0	5.8	[3] 4.8	5.8	5.5
70	......	......	6.7	6.8	7.4	7.5	6.5	6.5	7.1	6.9	6.9	6.8	5.7	5.7	5.8	6.1
90	......	......	7.0	6.8	7.1	6.3	6.6	6.5	6.7	6.3	6.8	6.6	5.9	5.9	4.9	5.2
110	......	......	6.6	6.5	5.9	6.0	5.6	5.9	5.6	5.6	4.7	4.9	3.7	3.7	2.5	3.4
130	......	......	5.2	5.7	4.8	5.0	4.4	4.4	3.5	4.3	3.0	4.3	([4])	([4])	([4])	([4])

[1] Determinations made by the Division of Fruit and Vegetable Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering, Charleston, S. C., and by the Grain Branch, Production and Marketing Administration, Beltsville, Md.

[2] U, uncompressed samples; C, compressed samples.

[3] This value appears to be too low, although 3 determinations showed good agreement.

[4] Discarded.

during the first 8 weeks, but there was a loss of approximately 15 percent when the storage was prolonged to 12 and 24 weeks. At the storage temperatures of 110° and 130° F. there was progressive loss, greater at the higher temperature, throughout the entire storage period. In the samples stored at 110° F. this loss amounted to over 50 percent at the end of 24 weeks, and in those stored at 130° F. the average was about 47 percent at the end of 8 weeks. In general, these findings parallel fairly closely the results of the quality tests, and show that with a loss in general acceptability there was a corresponding loss in thiamine values.

WHITE FLOUR

Samples of white flour containing 13.1 percent and 14.3 percent of moisture, respectively, were prepared for storage tests by compressing at pressures of 1,800 and 3,200 pounds per square inch. Compression procedure, material, and results were the same as those reported under the discussion of compression tests on this commodity. The compressed samples were packed in air-tight containers and stored together with similarly packaged samples of uncompressed material, some for 60 weeks at 70° and 90° F., and others for 37 weeks at 110° F. Analyses for fat acidity and organoleptic tests were made at intervals, and bread-baking tests were conducted to determine what effect, if any, compression had on the baking quality of the flours. The baking tests were made at the beginning and at the end of the storage periods.

The results of the fat acidity determinations are given in table 24, the data on the bread-baking tests in table 25.

Judged on the basis of fat-acidity values, the behavior of the compressed and uncompressed white flours at the two moisture levels of 13.1 and 14.3 percent, stored at different temperatures, did not differ materially. There was evidence that the compressed flours were deteriorating a little more rapidly than the uncompressed; the higher the pressure the greater the change, but it was not pronounced. Such differences as existed were most marked at the storage temperature of 110° F. There was also some indication that the flour having 13.1 percent moisture stored better than the flour containing 14.3 percent moisture.

It is to be noted that in none of the samples, compressed or uncompressed, were any off odors detected after storage at 70° and 90° F. for 60 weeks. A slight mustiness was observable in both uncompressed flours and flours compressed at 1,800 pounds per square inch after storage for 37 weeks at 110° F., but no mustiness was detectable in the samples compressed at 3,200 pounds per square inch. Although this response might indicate that compression at the higher pressure retarded the development of mustiness, it is believed that such conclusions should not be drawn until further investigations have been made.

TABLE 24.—*Fat-acidity values of compressed and uncompressed white flours of two different moisture contents held in storage at different temperatures for various periods*

Storage period (weeks)	Storage temperature	Fat-acidity values [1] of flour—		
		Uncompressed	Compressed at 1,800 pounds per square inch	Compressed at 3,200 pounds per square inch
13.1 PERCENT MOISTURE CONTENT				
	° F.			
0	70	43	....	....
	90	43	....	....
9	70	52	53	55
	90	58	63	66
16	70	55	56	57
	90	52	53	65
23	70	54	58	60
	90	67	74	73
48	70	68	70	73
	90	79	83	89
60	70	77	86	87
	90	89	99	101
0	110	26	....	....
3	110	39	43	45
25	110	72	82	113
37	110	[2] 69	[2] 78	113
14.3 PERCENT MOISTURE CONTENT				
0	70	43	....	....
	90	43	....	....
9	70	55	58	56
	90	62	71	65
16	70	52	58	60
	90	63	71	76
23	70	57	66	72
	90	71	79	88
48	70	65	77	79
	90	78	93	106
60	70	83	86	96
	90	79	107	121
0	110	26	....	....
3	110	36	41	42
25	110	64	100	89
37	110	[2] 66	[2] 100	89

[1] Expressed in milligrams of potassium hydroxide required to neutralize the free fatty acids in 100 grams of sample (moisture-free basis).

[2] Slightly musty

The results of the bread-baking tests (measured by loaf volume, grain texture, and crumb color) presented no evidence to indicate that compression, as applied in these experiments, injured or otherwise affected the quality of the flour for bread making. There was evidence of deterioration in baking quality

TABLE 25.—*Evaluation of bread baked from compressed and uncompressed white flours of two different moisture contents held in storage for different periods at various temperatures*

13.1 PERCENT MOISTURE CONTENT

Treatment of flour	Storage period	Storage temperature	Quality factors of bread		
			Loaf volume	Grain texture	Crumb color
	Weeks	°*F.*	*Cubic centimeters*	*Percent* [1]	*Percent* [1]
Uncompressed	0	....	836	85	90
Compressed at 1,800 pounds per square inch			853	85	95
Compressed at 3,200 pounds per square inch			830	90	95
Uncompressed	60	70	755	95	95
Compressed at 1,800 pounds per square inch			772	95	100
Compressed at 3,200 pounds per square inch			755	95	95
Uncompressed	60	90	689	95	90
Compressed at 1,800 pounds per square inch			680	90	95
Compressed at 3,200 pounds per square inch			(2)	(2)	(2)
Uncompressed	37	110	454	50	60
Compressed at 1,800 pounds per square inch			440	50	65
Compressed at 3,200 pounds per square inch			365	50	60
14.3 PERCENT MOISTURE CONTENT					
Uncompressed	0	....	865	90	95
Compressed at 1,800 pounds per square inch			848	90	95
Compressed at 3,200			833	90	90
Uncompressed	60	70	712	90	95
Compressed at 1,800 pounds per square inch			732	95	100
Compressed at 3,200 pounds per square inch			758	95	100
Uncompressed	60	90	612	90	85
Compressed at 1,800 pounds per square inch			617	95	90
Compressed at 3,200 pounds per square inch			(2)	(2)	(2)
Uncompressed	37	110	454	50	70
Compressed at 1,800 pounds per square inch			362	40	60
Compressed at 3,200 pounds per square inch			411	50	65

[1] Scored on basis of 100 as perfect.

[2] Not sufficient sample for test.

of the flour resulting from extended storage at elevated temperatures, but this was in accord with general experience that long storage at high temperatures adversely affects the baking quality of flour.

It was found that in making bread with compressed flour no different treatment from that used in connection with the uncompressed flour was required. The compressed blocks were placed in the mixer and given the same mixing treatment as the unpressed flour. It was not necessary to break or crush the blocks before processing into bread.

These preliminary findings indicate that compression of white flour under the conditions described may be entirely feasible and without adverse effect on quality.

WHOLE-WHEAT FLOUR

In the studies on whole-wheat flours the samples were prepared from materials containing 11.5 percent and 13.6 percent moisture; 5 percent of oat flour was added because of its antioxidant properties. As a control on the value of the oat flour in preserving quality, other samples were prepared from 13.6-percent-moisture material without the addition of oat flour. The blocks were made according to the procedure previously described in the discussion of compression tests on white flour. Pressures of 1,800 and 3,200 pounds per square inch were used.

The same storage temperatures and periods of storage were used as in the tests on white flours. All samples were stored in air-tight containers. Storage behavior was followed by determining fat-acidity values at various intervals and by conducting bread-baking tests.

Results of the fat-acidity determinations are given in table 26.

These results show that compressed whole-wheat flour, both with and without added oat flour, increased in fat acidity more rapidly than the uncompressed, and that the increase was greater the higher

Table 26.—*Fat-acidity values of compressed and uncompressed whole-wheat flours held in storage at different temperatures for various periods*

Description of sample	Storage period	Storage temperature	Fat-acidity values [1] of flour		
			Uncompressed	Compressed at 1,800 pounds per square inch	Compressed at 3,200 pounds per square inch
	Weeks	*°F.*			
Whole-wheat flour plus 5 percent oat flour; moisture content 11.5 percent	0	70	34	....	....
		90	34	....	....
	9	70	167	264	320
		90	227	347	360
	16	70	196	270	329
		90	232	334	346
	23	70	218	334	346
		90	250	353	363
	48	70	278	354	364
		90	251	352	358
	60	70	[2] 290	[2] 371	384
		90	[3] 255	[2] 336	357
Whole-wheat flour plus 5 percent oat flour; moisture content 13.6 percent	0	110	41	....	....
	3	110	153	227	250
	25	110	251	225	346
	37	110	[4] 250	[4] 332	406
Whole-wheat flour, no oat flour added; moisture content 13.6 percent	0	110	22	....	....
	3	110	118	155	178
	25	110	178	232	300
	37	110	[4] 161	317	343

[1] Expressed in milligrams of potassium hydroxide required to neutralize the free fatty acids in 100 grams of sample (moisture-free basis).

[2] Slightly rancid odor.

[3] Slightly rancid, musty odor.

[4] Slightly musty.

Table 27.—*Evaluation of bread baked from compressed and uncompressed whole-wheat flour containing 5-percent oat flour, unstored and stored at two different temperatures for 60 weeks*

Treatment of flour	Storage period	Storage temperature	Quality factors of bread		
			Loaf volume	Grain texture	Crumb color
	Weeks	*°F.*	*Cubic centimeters*	*Percent* [1]	*Percent* [1]
Uncompressed	0	....	594	70	20
Compressed at 1,800 pounds per square inch			597	65	20
Compressed at 3,200 pounds per square inch			591	65	20
Uncompressed	60	70	454	55	20
Compressed at 1,800 pounds per square inch			405	50	20
Compressed at 3,200 pounds per square inch			(2)	(2)	(2)
Uncompressed	60	90	306	20	15
Compressed at 1,800 pounds per square inch			323	20	15
Compressed at 3,200 pounds per square inch			(2)	(2)	(2)

[1] Scored on basis of 100 as perfect.

[2] Not sufficient sample for test.

the pressure employed in compression. For the samples stored at 110° F. the increase in fat acidity was somewhat less for the plain flour than for the samples that contained oat flour. It would appear from this observation that the use of oat flour with whole-wheat flour is valueless as an aid to retarding the development of fat acidity.

Results of the bread-baking tests (as indicated by loaf volume, grain texture, and crumb color) showed no differences in the baking quality of the compressed and uncompressed flours. The results obtained with the blend of whole-wheat and oat flours that contained 13.6 percent moisture are shown in table 27.

PRELIMINARY EXPERIMENTS ON THE USE OF IN-PACKAGE DESICCANTS WITH COMPRESSED DEHYDRATED FOODS

Investigations conducted under another project at the Western Regional Research Laboratory have shown that the storage lives of certain uncompressed dehydrated foods can be materially increased by including a suitable desiccant[8] in containers in which the food is hermetically sealed for shipment. Through the use of a reasonable quantity of desiccant it was found possible to reduce the moisture content of the uncompressed products to considerably lower levels than are economically attainable by conventional dehydration processes. In view of the longer storage life afforded by this method it seemed advisable to determine whether desiccants can also be used to advantage in packing compressed dehydrated foods, and to this end a series of experiments was initiated. However, because of termination of the project it was possible to complete only a few exploratory tests. It is therefore emphasized that the data here presented are definitely preliminary in nature and of value only as guideposts in setting up more comprehensive experiments.

Compressed packs of diced carrots, shredded cabbage, and egg powder were employed in the tests. Details of packing are given in table 28.

The lime used met the performance requirements established in the studies on uncompressed foods. It was contained in corrugated paperboard boxes large enough to provide for 30 percent expansion of the lime on hydrating; that is, the space allowed was 2.96 cubic centimeters per gram (0.047 cubic foot per pound) of lime present.

In setting up the packs the lime containers were placed at the bottoms of rectangular cans measuring 3 by 5 inches in horizontal cross section. Two or three of the compressed food blocks, each wrapped in medium-weight kraft paper, were then tightly packed in the cans with the 3- by 5-inch block surfaces facing the desiccant container. The clearance between block and can sides was very small, so that the conditions were similar to those that would probably obtain in packs of commercial size. The maximum distance from the food to the top of the 3- by 5-inch desiccant containers was either two or three times the thickness of one block, depending on the number of blocks in the container. One can for each of the compressed packs was equipped with a stopcock so that it could be evacuated, and a second can was hermetically sealed at atmospheric pressure by soldering the lid. The tightly fitted blocks prevented collapse of the evacuated cans.

TABLE 28.—*Comparative moisture contents, sizes, and densities of 1-pound blocks of compressed dehydrated carrots, cabbage, and egg powder packed with lime as a desiccant*

Food	Initial moisture content	Approximate dimensions of block	Block density	Lime used per pound of food
	Percent	*Inches*	*Pounds per cubic foot*	*Grams*
Diced carrots[1]	5.5	1¾ by 3 by 5	67	6[illegible]
Cabbage flakes	4.3	2 by 3 by 5	60	63
Egg powder	5.1	2⅕ by 3 by 5	50	71

[1] Size of dice approximately ⅜ by ⅜ by 3/16 inch.

The egg-powder packs were stored at room temperature and the vegetables at 100° F. The lower temperature was used for the egg powder because its quality deteriorates very rapidly at higher temperatures, particularly when it contains 5-percent moisture. At regular intervals the blocks were removed from the cans and weighed to determine the loss in moisture. They were then immediately replaced in the containers in the original order and storage was continued after reestablishment of the pressure conditions imposed at the outset. The pressure in the evacuated cans was reduced to 2 or 3 millimeters of mercury at the start of each test period. Data on drying rates for the various packs are summarized in table 29.

In the tests the packaged foods were [illegible] to the fumes of soldering and other [illegible] each time the blocks were removed from storage and weighed; it was therefore [illegible] attempt to evaluate [illegible] quality after storage. However, comparison of the drying rates [illegible] in these tests with those in the much more [illegible]

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[8] Experiments on the rate of moisture removal, correlated with the degree of protection against high-temperature storage, showed that calcined lime in tightly woven canvas bags or in strong fiberboard cartons is a satisfactory desiccant for uncompressed dehydrated foods, provided it is so prepared as to meet the following minimum performance requirements: The packaged lime should increase in weight by not less than 28.5 percent in 48 hours when placed in a closed container over a saturated solution of sodium bromide at 24° C.; in addition to being reasonably permeable to water vapor, the lime containers must be sift-proof, resistant to abrasive action under shipping conditions, and of sufficient volume and strength to withstand the pressure exerted by the expanding mass of hydrating lime.

TABLE 29.—*Moisture contents of food blocks stored in sealed containers containing calcined lime*

COMPRESSED CABBAGE SHREDS STORED AT 100° F.

Days in storage	Moisture content [1]					
	Vacuum pack			Air pack		
	Bottom block	Center block [2]	Top block	Bottom block	Center block	Top block
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
0	4. 3	....	4. 3	4. 3	4. 3	4. 3
2	3. 0	....	3. 0	....	....	....
11	2. 3	....	2. 3	3. 5	4. 2	4. 3
45	1. 8 (1. 3)	....	1. 8 (1. 3)	2. 6	3. 4	4. 3
70	....	....	....	2. 3 (1. 7)	3. 0 (2. 7)	3. 5 (3. 3)
COMPRESSED EGG POWDER STORED AT 75° F.						
0	5. 1	....	5. 1	5. 1	5. 1	5. 1
2	2. 5	....	2. 7	....	....	....
6	1. 9	....	2. 0	....	....	....
11	1. 5	....	1. 7	4. 6	5. 0	5. 1
24	1. 4	....	1. 5	....	....	....
45	0. 5 (0. 9)	....	0. 6 (1. 1)	3. 6	4. 5	5. 0
79	....	....	....	3. 3 (3. 3)	4. 3 (4. 2)	4. 7 (4. 6)
COMPRESSED DICED CARROTS STORED AT 100° F.						
0	5. 5	5. 5	5. 5	5. 5	5. 5	5. 5
3	4. 4	4. 4	4. 6	....	....	....
11	3. 6	3. 6	3. 7	....	....	....
14	....	....	....	3. 9	4. 7	5. 2
18	3. 3	3. 3	3. 4	....	....	....
27	....	....	....	3. 2	3. 9	4. 4
32	3. 1	3. 1	3. 2	....	....	....
57	....	....	....	2. 9	3. 5	3. 3
63	3. 0	2. 9	2. 9	....	....	....
82	3. 0 (3. 1)	2. 9 (2. 9)	3. 0 (3. 1)	....	....	....
105	....	....	....	2. 6 (3. 3)	3. 2 (3. 5)	3. 1 (3. 4)

[1] The initial moisture-content figures and the final figures, shown in parentheses, were determined by analytical methods; other values were calculated from weight losses of blocks.

[2] Only 2 blocks of cabbage and egg powder were vacuum-packed in a can, with no clearance between blocks.

sive studies previously conducted on uncompressed dehydrated foods indicate that under certain conditions the use of the lime desiccant with compressed products will permit considerably longer storage. For instance, the rate of drying in all three evacuated packs containing compressed blocks appears to be sufficient to produce a very beneficial effect. The same tentative conclusion appears to be applicable to the compressed diced carrots and shredded cabbage packed in air. However, the rate of drying obtained at 75° F. with the air-packed egg-powder blocks is believed to be too slow to have any material effect on storage life.

The data given in table 29 show that for the air packs the drying rate decreased as the distance from food to desiccant increased, whereas for the evacuated packs the drying rate appeared to be practically constant regardless of the block position. Thus, for nonevacuated packs it would be advisable to avoid long distances between food blocks and desiccant. In packing 5-gallon containers this distance could be kept small by placing a flat pad containing the required amount of desiccant between every two or three layers of blocks. Possibly this procedure would also be advisable for evacuated packs in which the conditions differ from those in the tests considered here. It is doubtful, however, whether it would be practical to evacuate large containers unless they were made of material that prevents buckling. On the other hand it may be that only partial evacuation of the containers will lead to satisfactory acceleration of drying rates and that large containers of conventional design can be used if tightly packed.

Obviously, the space occupied by the lime desiccant reduces the amount of food that can be packed in a given container. Simple calculations readily give the approximate reduction incurred. A 5-gallon can of compressed diced carrots, for example, if allowance is made for 10 percent of unused space (loss at top and corners), will contain 39 pounds of material in block form when the block density is 65 pounds per cubic foot and no desiccant is added. If lime desiccant is added at the rate of 13.9 pounds per 100 pounds of food and 0.047 cubic foot of space is allowed for each pound of packaged lime, there will be 72.4 percent of the can space available for the compressed food. Then, making allowance for a 10-percent loss of space in placing the blocks, the 5-gallon can will contain 28 pounds of food and 3.9 pounds of lime. Thus the desiccated pack contains 28 percent less food than the undesiccated compressed pack. Nevertheless, considering that uncompressed diced carrots are conventionally packed without desiccant at the rate of 20 pounds per 5-gallon can, it is apparent that the compressed pack with the desiccant represents a considerable improvement.

PEACETIME COMPRESSION

It is still not possible to tell just how profitable compression of dehydrated foods may prove to be in peacetime, but in certain situations and conditions it would be of decided advantage. During World War II the prime objective of compression was reduction in bulk in order to save shipping and storage space, and in peacetime this is still a prime consideration. Satisfactory warehouse space for the storage of food is likely to be expensive, and it is often inadequate. Wherever compression is feasible warehousing costs can be reduced, and compactly packaged units make for ease and economy in handling.

Under some conditions compression of food would reduce transportation costs. The bulk of uncompressed dehydrated products is so great compared with their weight that a standard railroad car will not handle a minimum carload and a ship cannot be loaded to the standard stowage factor of 40 cubic feet per ton. Most compressed products are sufficiently high in density to permit a much closer approach to ideal rates of loading.

Another advantage of compression is that an impervious package, which is essential to long storage life, can be provided more readily and cheaply for a product of high density than for a bulky one.

Compressed food would be particularly advantageous where high temperatures prevail. Experimental evidence shows that the higher the storage temperature, the shorter the useful life of the dehydrated product. If prevailing temperatures are so high that cool or cold storage must be provided, compressed products obviously have an advantage because of the smaller space required. This would hold true for foods handled by warehouses, ships, and trains in tropical and semitropical regions. The compressed products would also be particularly adapted to use in mining or other camps far removed from ready sources of food supplies, and their compact form would facilitate their transportation in unsettled regions.

High density, however, is but one of the considerations that will determine the future of compressed foods as standard peacetime commodities. For compressed dehydrated foods to succeed they must:

1. Be palatable when reconstituted.
2. Have high nutritive value.
3. Have a pleasing appearance.
4. Be easy to prepare.
5. Maintain desirable properties for a considerable length of time when stored in available facilities.
6. Be available in units adapted to the needs of the consumer.
7. Be reasonable in cost.

Where these requirements are met by the manufacturer of compressed dehydrated food, a market for his products will be assured.

UNSOLVED PROBLEMS

Some of the problems encountered during the compression work could not be solved because of limitations of time, personnel, and equipment and the complexity of the factors involved. It may be useful, however, to know what these problems are, even if the solutions must await further work. Considered as a whole, the problems fall into two groups—those that concern the design of equipment and the development of processing methods that will make commercial production economically feasible, and those that apply to the development of processes that will improve the quality of certain products. Particularly deserving of study in any further researches are:

1. The conditions that will permit compression at shorter dwells than used in these studies.
2. Precompression conditioning operations, with special emphasis on equipment required for establishing uniform distribution of moisture in freshly dehydrated products, and optimum temperature, humidity, etc., for each commodity.
3. Improvement of equipment used to restrain expansion of blocks during post-compression cooling. Holding presses used in this operation should be of such design that a minimum of hand labor is required

4. Development of presses that will enable compression to be carried out rapidly and economically. In this connection the following questions, together with a discussion of the factors that must be taken into account in answering them, are pertinent:

a. What changes in design are required to increase the production capacity of conventional types of block-forming presses?

The present custom of conducting mold-charging, pressing, and ejecting operations in a single position between the pressing platens prevents the attainment of high production rates. It would seem possible to develop a press in which the pressing operation only is conducted between the platens while filling and ejecting operations on other integral molds are being simultaneously carried out. A design incorporating a circular table that rotates stepwise in a horizontal plane and contains three mold boxes disposed at 120° intervals may be a possibility. Each movement of the table could move the three molds successively to the charging, pressing, and ejecting positions.

b. Can press costs be reduced by simplifying design?

It was found that results with molds of the floating type are not significantly better than those with fixed-mold-box types. Molds of the latter type are simpler and cheaper to construct and therefore preferable for food-compression work.

In compressing materials other than powders it was found that grooving of molds is not essential provided satisfactory clearance is maintained between the male die and mold-box walls. It is consequently believed that this elaboration is unnecessary when the press is to be used for compression of materials of moderately large piece size.

Hydraulic presses are desirable in food-compression work because they can be provided with simple means for accurate control of applied pressure. However, they are generally slow acting, and any attempt to increase rate of ram travel by hydraulic means results in much higher equipment costs. Since it appears that ram travel can be very rapid when compressing properly conditioned materials other than powders, and since production capacity increases with an increase in the rate of ram travel, it would appear desirable to design a food press in which the ram is moved by hydraulic means over the final portion of the stroke only. In such a design the ram would be moved very rapidly through the low-pressure portion of the stroke by a lever or knuckle-joint mechanism, and the high-pressure portion of the stroke would then be completed by the usual hydraulic means.

c. Are radical changes in compression equipment desirable?

For example, it may be profitable to develop a forming press that produces a continuous sheet of compressed material and subsequently reduces the sheet to rectangular pieces which could be packed layerwise in the distribution container. A few preliminary experiments have indicated that wafer-thin blocks (about one-fourth inch thick) can be formed successfully from vegetable strips or dice without excessive fragmentation and that these disintegrate very rapidly in water.

5. Further development of equipment and methods for compressing powders and noncohesive materials directly in the containers used for distribution.

6. Development of commercially practicable molds of the vacuum type for rapid compression of powdered materials.

7. Development of containers in which compressed rectangular blocks may be efficiently packed. The conventional round-cornered can is not well suited to compressed products. A can with right-angle corners would permit more complete utilization of space and round-cornered blocks would not be necessary. Since optimum block density is different for different commodities and since density is controlled by altering block thickness only, containers that are to be used for several kinds of compressed foods should provide for packing in such a manner that the block thickness dimension is always perpendicular to the base of the can.

8. Improvement of methods for compressing, drying, and rehydrating compressed blocks of potatoes.

9. Suitable dimensions and densities for blocks of lesser and greater weight than those prepared in the investigations reported here. In supplying the civilian market it will be desirable to provide blocks suited to institutional use and also to the needs of the small consumer. The densities and dimensions of the larger and smaller blocks should be such as to permit rapid rehydration without damage to quality.

10. The effect of block-cooling rates on product quality and full development of means for economically attaining desirable rates of cooling.

11. Rehydrating and cooking techniques for best table quality.

12. The comparative storage properties of compressed and uncompressed dehydrated foods from the standpoint of nutritive value and organoleptic quality.

13. The usefulness of in-package desiccants, with special emphasis on the correlation of the rate of moisture removal and the degree of protection attained under conventional storage conditions. A study of this kind should include both evacuated and gassed packs. The rate of diffusion through a gaseous

medium increases as the molecular weight of the gas decreases. Thus, rates of moisture removal in packs containing helium should be investigated, since these rates will be greater than for a heavier gas, such as nitrogen, where the rate of diffusion through the gas is the factor that controls the rate of moisture transfer from food to desiccant.

14. Methods for compressing vegetables and fruits that are only partially dehydrated and subsequently frozen and stored at subzero temperatures; that is, compression procedures for "dehydrofrozen" products (*3*).

The need for solving these remaining problems depends mainly on the degree to which the demand for dehydrated foods will be maintained in time of peace and the possible occurrence of another emergency wherein large quantities of dehydrated products would be required.

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